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OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: March 26, 1980

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Project Director: J. L. Clark

Sponsor: Madison Industries, Inc. of Georgia; Conyers, GA

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Sponsor Contact Person (s):

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SPONSORED PROJECT TERMINATION

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Project Title: Passive and Hybrid Solar Manufactured Housing and Buildings

Project No: A-2582

Project Director: J. L. Clark

Sponsor: Madison Industries, Inc. of Georgia; Conyers, GA

Effective Termination Date: 3/31/81

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Grant/Contract Closeout Actions Remaining:

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FINAL REPORT

A PASSIVE DESIGN FOR A MANUFACTURED CLASSROOM BUILDING

Submitted by

MADISON INDUSTRIES INC. of GEORGIA
and
GEORGIA INSTITUTE of TECHNOLOGY
Engineering Experiment Station

March 31, 1981

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1. INTRODUCTION

This report is a summary of work conducted by Madison Industries Inc. of Georgia and the Georgia Institute of Technology Engineering Experiment Station toward the development of passive solar heating systems for manufactured buildings. The specific application is a modular classroom building.

Four passive system concepts were selected for space heating. These concepts are as follows:

(1) Direct Gain
(2) Water Wall
(3) Sunspace
(4) Integral Collector Wall

Designs were prepared for all four concepts. Thermal analyses were conducted, including annual heating simulations, for all designs. Typical weather and solar data for Atlanta were used in the simulations. In addition, design features for daylighting were incorporated in the building.

A complete set of drawings of the final building design has been prepared and submitted to the program sponsor separate from this report. References to these drawings are made in the report.

2. MANUFACTURED BUILDING CONSTRUCTION

Madison Industries Inc. of Georgia utilizes structural steel post and beam frame construction with a unique (Mideck) steel panel system for both roof and walls. Mideck interlocking panels are roll-formed from galvanized sheet at the Madison plant. Madison manufactures both modular buildings with structural steel floor systems and panelized buildings which are erected on the site on concrete slabs. Modular buildings have either wood or light-weight concrete subfloors. Buildings are delivered to the site on Madison trucks and erected by Madison field crews. Madison plants have manufactured a variety of fast food restaurants, service stations, mini-storage warehouses, residences, and classroom buildings.

3. MANUFACTURED BUILDING APPLICATION

The members of the design team from Madison Industries Inc. of Georgia and the Georgia Tech Engineering Experiment Station have selected a classroom building design on which to incorporate passive solar techniques. These buildings will be sold to public school systems in areas where rapid population growth has caused overcrowding of schools and brought about the need for additional classrooms at existing schools. Among the many school districts across the country experiencing these problems are Gwinnett County, Georgia; Hillsborough County, Florida; Harris County, Texas; and San Diego County, California. Many school systems including several in the State of Georgia have been utilizing trailers as classrooms. These modular or panelized classroom buildings manufactured by Madison would provide relocatable classrooms similar in size and layout to existing classrooms.

Madison plants in the Southwest have had experience in marketing and manufacturing these classroom buildings and have investigated manufacturing entire school facilities. The Madison Georgia plant will initially concentrate on the State of Georgia Department of Education and the Rockdale County School District (where the plant is located). An initial meeting with representatives of the Georgia Department of Education in November, 1979, revealed considerable enthusiasm for passive heating and modular construction. The state has consistantly encountered unexpectedly high energy costs, making passive heating and energy conservation increasingly more attractive. The changing population distribution also dictates a continuing need for new classroom space in growing counties even though the number of children attending public schools is expected to decline. In a more recent discussion, the Rockdale County school system indicated an interest in the passive manufactured classroom concept and revealed a need for 4000 square feet of additional classroom space in the coming year. In addition, Madison Industries will have opportunities to introduce the passive classroom concept to the private and parochial sector.

The heating requirements for this application differ from those of a residence, therefore, analysis techniques developed for residential use are not directly applicable for a classroom building. The building will only be occupied during normal school hours on weekdays. Morning heat-up will be important; building orientation and passive design features may be optimized to increase the solar contribution to morning heat-up. Thermal storage will not be important for overnight heating. Thermal storage will be important in some cases for controlling afternoon overheating. These buildings will not be used during the summer quarter; so summer overheating will not be a major concern.

The one-story manufactured building is 33' x 60' with a gross area of 1,980 sq ft. The walls are insulated with fiberglass batt and are painted steel or 3/4" brick veneer on the exterior. Fiberglass insulation (R-19) is used above the suspended ceiling. The floor is a poured concrete slab with 2" rigid foam, perimeter insulation.

4. DESIGN AND ANALYSIS TOOLS

The modeling of passive utilization systems is inherently more difficult than the modeling of active systems because passive structures are closely coupled to their load and because they rely on diffusion or bouyant convection to transfer energy to the conditioned space.

A number of modeling techniques are available to treat active systems ranging from simulation programs such as TRNSYS[1] to the utilization techniques [2,3] and the design-chart methods, most notably FCHART[4]. The same range of methods is potentially available to treat passive systems where the simulation methods are represented by programs such as DEROB/PASOLE and the design chart methods are most notably represented by the SLR method developed at Los Alamos Scientific Laboratories[5] and the PFCHART program advanced by the Northeast Solar Energy Center[6].

The system modeling used in this project initially relied on direct application of the SLR method and exercise of a version of PFCHART made available by the Southern Solar Energy Center. While this work is felt to have been instructive to the early phases of our work, reliance on these related methods was felt to be unadvisable for the following reasons:

(1) The primary application is anticipated to be a modular classroom building for which the afternoon and early evening heating loads and weekend loads are discounted since the building would not be occupied at these times.

(2) For the modular classroom, the internal heat generation is unusually large. The design process becomes one of efficiently providing for early morning warming without excessive overheating during the afternoons.

It was expected that a version of DEROB[7] would be available to assist in the modeling of this somewhat non-standard building during the course of our project; however, this did not come about. The design team was in consequence faced with the problem of developing a design without recourse to applicable design guidelines and of evaluating the design in the absence of an accepted, validated simulation program.

The obvious solution was to develop a simple thermal-analysis program that could simulate the response of our building to typical solar resources and weather under the expected conditions of use. Of necessity since weeks rather than months were available to develop this program it could not be detailed; furthermore, a detailed program would undoubtably be too consumptive of computer time to allow the quick solutions necessary during the design process. The result of this effort is a program called PASSSY (for Passive Systems Simulation) characterized by the following features:

(1) PASSSY uses a simplified version of the standard SOLMET typical year data. The format is greatly condensed to allow storage on a disc file and solar angles are included with the data eliminating the repetition of geometric calculations.

(2) PASSSY is currently configured to consider a network of six thermal capacitances. Three of these are used to represent the thermal mass in a water wall or sunspace, one represents the conditioned space and closely-coupled mass, and the remaining two are used to represent the envelope of the building. Since all six nodes are capacitive, strictly algebraic heat conduction equations are eliminated. A system of finite-difference equations results.

(3) Solar gain is computed allowing for two-dimensional shading of the solar wall by any roof overhang which is conservative for heating performance. Incident angle effects on the transmittance-absorptance of the aperture is handled directly as a function of incident angle at the glazing.

(4) A series of logical evaluations represents the expected control functions whether effected by the space thermostat or intervention by the occupants.

(5) An effort was made to assess the effectiveness of daylighting in the building.

(6) PASSSY operates with a variable time increment which allows an estimate of the accuracy of the numerical integration. For thirty increments an hour (the production interval) about 175 CP seconds are required on the CDC CYBER 70. This represents about five minutes when performed interactively on the timesharing system.

The thermal network used to represent the passive system is shown in Figure 1. There are six thermal capacitances representing the following:

C1: thermal mass in a water wall (WW) or sunspace (SS) exposed to irradiance and loss to the environment

C2: thermal mass internal to the WW or SS

C3: thermal mass in the WW or SS exposed to the conditioned space

C4: thermal mass in the conditioned space comprising air, furnishings, and interior surfaces, also the mass exposed to direct gain

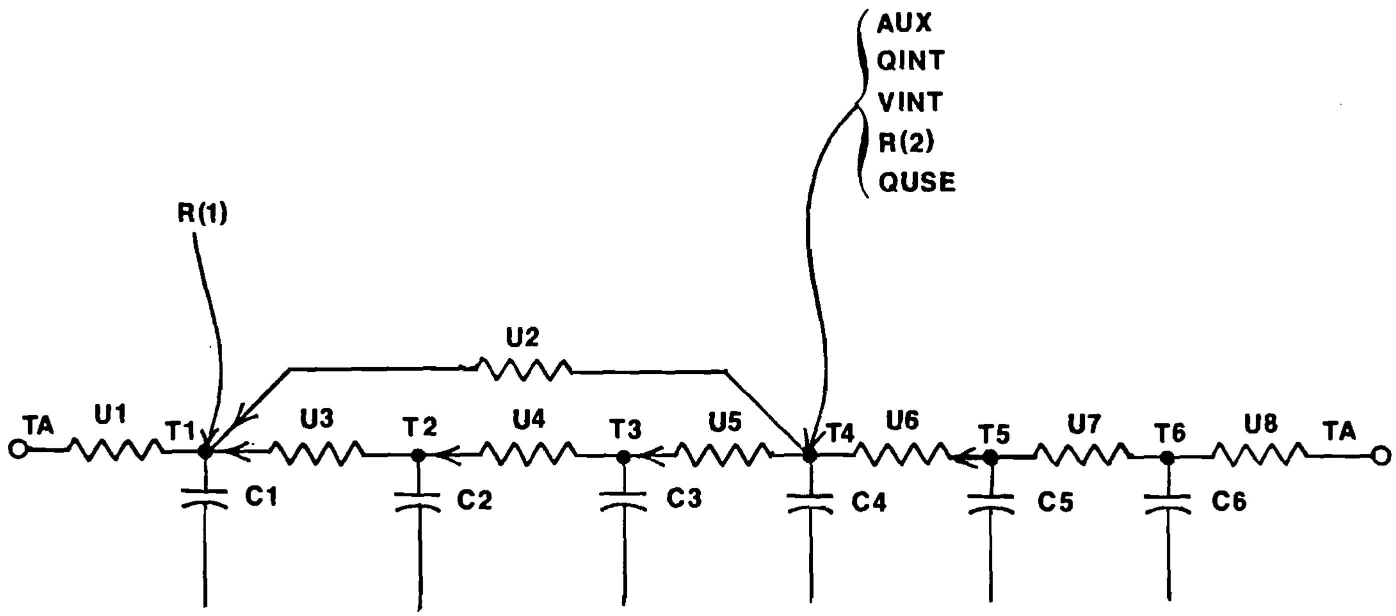


Figure 1 Thermal Network

C5: thermal mass representing the core of the building envelope

C6: thermal mass representing the exterior surfaces

It should be noted that C4 is considered to include the interior paneling of the building since we note that in reasonably well insulated buildings wall temperatures approximate the air temperature. This approximation appears reasonably justified for modern, conservative construction and avoids numerical difficulties resulting when the relatively low thermal capacitances of the air space alone is strongly coupled by a large thermal conductance to the interior surfaces. For the same reasons, C6 representing the exterior surface was fixed at the outside temperature. Again, this is in accord with experience and leads to a more stable numerical simulation. For the simple water wall system, the parameters for C1 through C6 are as given in Table 1.

The most important parameters in the network are the thermal conductances. The eight thermal conductances represent the following effect:

U1: loss from the exposed thermal mass to the environment as modified by moveable insulation at night, under low irradiance, or when the space is overheated.

U2: bouyant convection from the exposed mass to the space with allowance for forced convection and backdraft damping

U3: diffusion in the thermal mass

U4: diffusion in the thermal mass

TABLE 1

THERMAL MASSES IN BASELINE CASE

PARAMETER	VALUE PER UNIT WATER WALL ($BTU/F^o/ft^2$)	BASIC VALUE NON-SOLAR (BTU/F^o)	REMARKS
C1	12.48	0	1/5 of 12 inch water wall
C2	24.96	0	twice C1
C3	24.96	0	twice C1
C4	-0.33	2907	interior, user may augment
C5	-0.74	4186	core of envelope
C6	-0.44	1293	skin

U5: bouyant convection from the interior thermal mass to the conditioned space

U6: loss from the conditioned space (i.e. interior paneling) to the core of the building envelope

U7: loss from the core of the envelope to the exterior skin of the building

U8: loss from the skin to the environment. Since this term is rather large, it was approximated as unbounded by fixing the skin temperature at ambient temperature

The best estimates achieved for these parameters are listed in Table 2.

Several heat inputs or losses are also involved in this simulation as illustrated in Figure 1 and defined below:

R(1): irradiance absorbed by the exposed mass. This is modified by a representative functional dependence of the transmittance-absorbtance product on incident angle.

R(2): irradiance absorbed by surfaces in the conditioned space (i.e. direct gain irradiance). Also modified for the transmittance-absorbtance of the glazing and surfaces.

AUX: auxiliary heating or (when needed and effective) ventilation.

QINT: internal generation of heat from occupants. Heat from illumination has been disregarded in view of daylight utilization.

TABLE 2
WATER WALL UNIT CONDUCTANCES

PARAMETER	VALUE PER UNIT APERTURE $(BTU/HR/FT^2/F^\circ)$	ALTERNATE VALUE $(BTU/HR/FT^2/F^\circ)$	BASIC VALUE NON-SOLAR $(BTU/HR/F^\circ)$	REMARKS
U1	0.58	0.13*	0	double-glazed, R6 NI, Kleins top-loss formula
U2	2.0	0.0*	0	bouyant convection
		4.0**	0	forced convection
U3	0.9	0.9	0	diffusion in WW 4.8 inch spacing
U4	0.9	0.9	0	same as U3
U5	0.81	0.81	0	diffusion and bouyant convection
U6	0.98	0.25*	685	twice building UA with allowance for DG aperture
U7	0.98	0.25*	685	same as U6
U8				assumed large

*with night insulation, R6
**with forced convection

VINF: heat loss by infiltration and necessary ventilation.

QUSE: heat gain by the integral collector wall modeled by the Hottel-Whillier-Bliss equation [6].

PASSSY is organized as illustrated in Figure 2. An executive program interfaces with the user, various subroutines, and the weather/solar data. A simple first-foward difference integration is utilized. In selecting a time increment, runs were made at 1, 5, 15, 30, 120 and 500 intervals per hour. A 12% difference in heating load was evidenced between 1 and 500 intervals for a typical January but there was only a 0.7% difference between 15 and 500 intervals and only a 0.4% difference between 30 and 500 intervals. A selection of 15 or 30 intervals per hour thus seems adequate.

As outputs PASSSY produces the following:

(1) A daily record of the simulation giving absorbed irradiance, average temperatures of the nodes, and temperature extremes in the space along with other data.

(2) An annual summary.

(3) A monthly histogram of the auxiliary heating required. This is a useful tool in selecting orientation and surface finishes.

(4) Selected days are illustrated by hourly simulation results that indicate the dynamic response of the system.

A listing of PASSSY is included as an appendix.

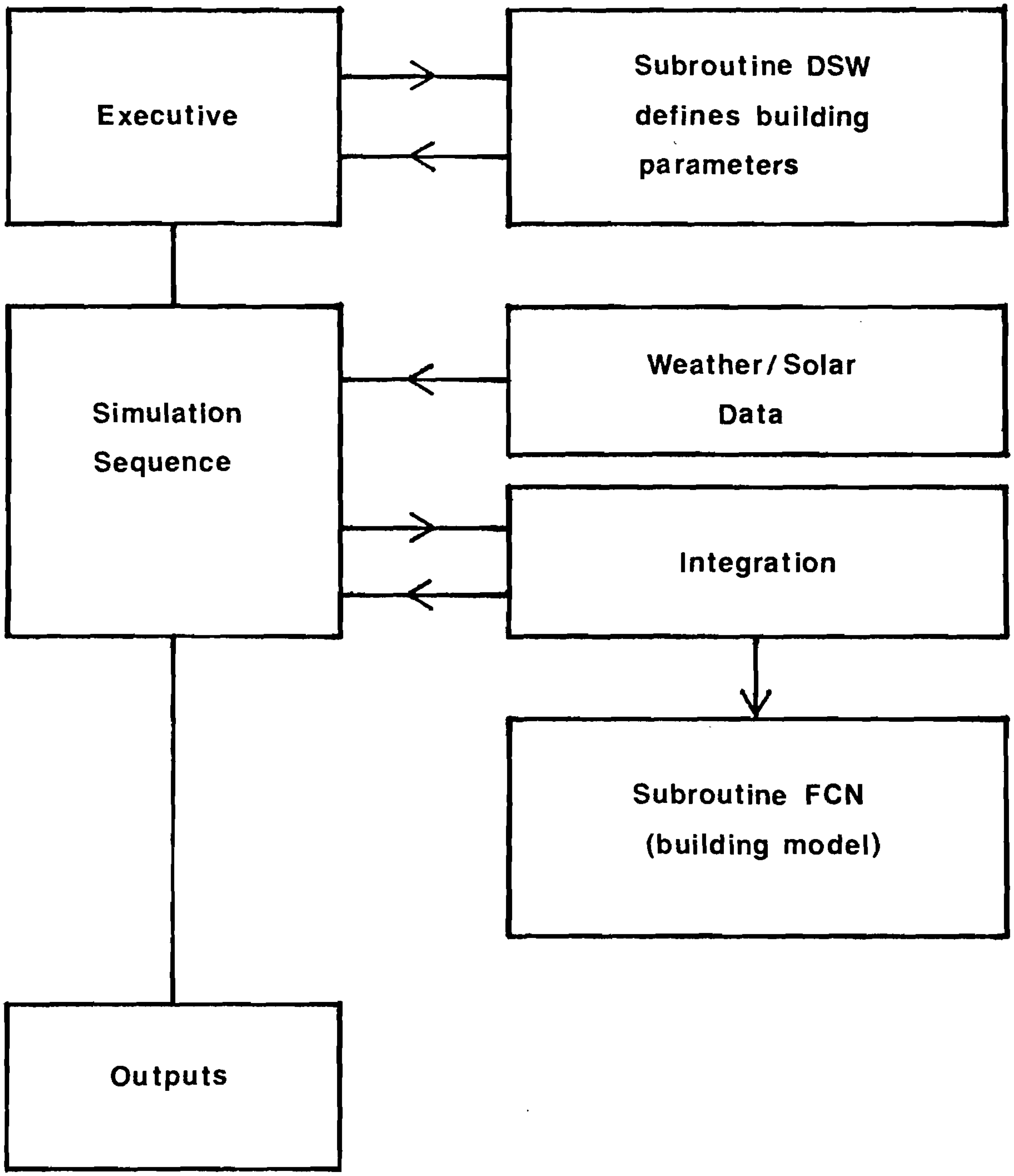


Figure 2 Basic Outline of PASSSY

5. PASSIVE SOLAR DESIGN ALTERNATIVES

A number of passive solar design features were considered for this manufactured building application. The design team reviewed various passive techniques for space heating and cooling, domestic hot water heating, and daylighting as well as for desiccant dehumidification. Space heating techniques included the shallow roof pond, thermal storage wall, attached sunspace or greenhouse, remote collectors, wall-integral thermosiphoning air collectors, and direct solar gain. Passive cooling using a shallow roof pond and moveable insulation was considered. These techniques are presented in an evaluation matrix for comparison in Figure 3.

A number of criteria were used to judge these possible passive techniques. Certain criteria were considered more important than the rest. These criteria included applicability to the classroom building loads, difficulty of implementation using Madison's standard construction techniques, and usefulness in the climate of the Southeastern and Eastern United States. The minimal nighttime heating load of the building reduces the importance of thermal mass for storage. Madison Mideck roof and wall panels are ideal for shallow solar ponds and as the basis for an integral collector wall. Eastern climates have winters ranging from mild to severe while having hot and humid summers. Cooling loads are high, but nighttime sky conditions do not favor passive radiative cooling techniques such as the roof pond with moveable insulation. Dehumidification is a large part of the cooling load but the feasibility of passive desiccant dehumidification has not been proven.

Four passive solar space heating techniques were chosen for design concept development. They are direct solar gain, water wall, attached sunspace or greenhouse, and an integral solar

	technical feasibility	performance potential	economic potential	aestetics	relocatability	effect on cooling	controllability	response time	maintenance	reliability	durability	safety	usable space	simplicity	overheating
Direct Gain w/ movable insulation	E	G	E	G	N	G	G	E	E	E	E	N	N	G	P
Sunspace	E	G	G	G	P	N	E	G	E	E	E	N	E	G	E
Water Wall	E	E	E	G	N	G	G	G	E	E	E	E	N	G	G
Thermal Mass Wall	E	G	G	G	P	G	G	G	E	E	E	N	N	G	G
Integral Collector Wall	E	G	G	G	N	G	E	E	E	G	E	N	N	G	G
Roof Pond	E	P	P	N	N	G	G	P	G	G	G	E	N	G	G
Roof Pond w/ movable insulation	G	P	P	N	N	G	E	P	G	G	G	E	N	P	G
Remote Collector	P	P	P	N	X	G	G	G	G	G	G	N	N	G	G
Dehumidification	G	X	X	N	N	G	G	G	P	P	P	N	N	P	G
Daylighting	E	E	E	E	N	G	G	E	E	E	E	N	N	E	G
Domestic Water Heating	G	G	G	N	N	E	E	G	G	E	E	G	N	G	E

E - excellent

G - good

N - neutral

P - poor

X - unproven

Figure 3 Passive Technique Evaluation Matrix collector wall. The Georgia Tech design team presented these four concepts, along with the general building application, to an advisory panel of Georgia Tech personnel from several solar energy fields. Participants in this meeting agreed that these four concepts merited development. The meeting was useful for pointing out specific concerns for each of the concepts and for identifying the integral collector wall as an especially promising alternative.

These four concepts were developed from this point. Madison Industries provided the initial building design, specifications, and heat loss calculations. Madison Industries and Georgia Tech personnel worked together exploring ways to implement these four passive techniques into Madison's construction methods. Georgia Tech personnel performed the preliminary thermal analyses and investigated specialized construction materials. These four designs are discussed in following sections of this report.

5.1 Direct Gain System

A passive solar system using direct gain of sunlight by the building is one viable method for heating the classroom building. The direct gain system is simple, using glazing on the south wall of the building and incorporating mass in the floor to store and release heat.

Building Construction

The building will incorporate glass on the south wall to allow for direct gain of solar energy. The amount of glass required is discussed later in this section, but for structural considerations and storage of movable insulation panels, would be limited to less than 67% of the south facade. A 2' wide overhang provides shade during the early fall, late spring, and summer months to prevent overheating.

The building is oriented so that the glazed wall is within 20° east of facing due south to catch early morning sun when heating is needed. Drawing C2 shows a planview of the direct gain design.

The moveable insulation panels are on sliding tracks. The interior is a gypsum panel or other fire resistant finish. The exterior, which faces the inside of the glazing, is a rigid foam or fiberglass insulation board. The foam insultion may be painted white or foil faced to reflect sunlight and combat infrared heat loss. The sliding panels are trimmed with metal moulding to resist damage and provide a surface for weatherstripping to seal on.

System Operation

A direct gain system relies on the low angle of the winter sunlight to project this light and heat on the floors and walls of the classroom. Movable insulation or shutters and blinds are used to control the amount of light, combat overheating, and cut heat loss at night. Interior surfaces which absorb the sunlight should be dark, but need not be black, and should have the ability to store heat. Low thermal mass surfaces should be light colored to reflect and disperse sunlight throughout the classroom.

System Viability

The direct gain system is among the simplest and least costly solar heating systems available. The sunlight can also provide roomlighting and reduce the need for artificial light.

Direct gain system have drawbacks, however. The strong and changing amount of sunlight can cause glare in the room. Direct gain on the students themselves may cause physical discomfort. High heat loss can result on cloudy and cold days and at night.

These problems can be minimized by using movable insulation systems and glazings which diffuse and distribute the sunlight. This results in higher costs but more control. While automatic control of an insulating panel or blind can be used, the resulting cost and complexity are not warranted where students and teachers can interact with the system. A variable level lighting system which senses sunlight levels and regulates the artificial lighting is recommended.

Performance Simulation

A computer simulation of building heating load and solar system performance was run for the direct gain system using typical January weather and solar data. Figure 4 presents the solar fraction (percentage of total heat requirement supplied by solar) versus aperture area. With 60% (283 ft^2) of the south facade

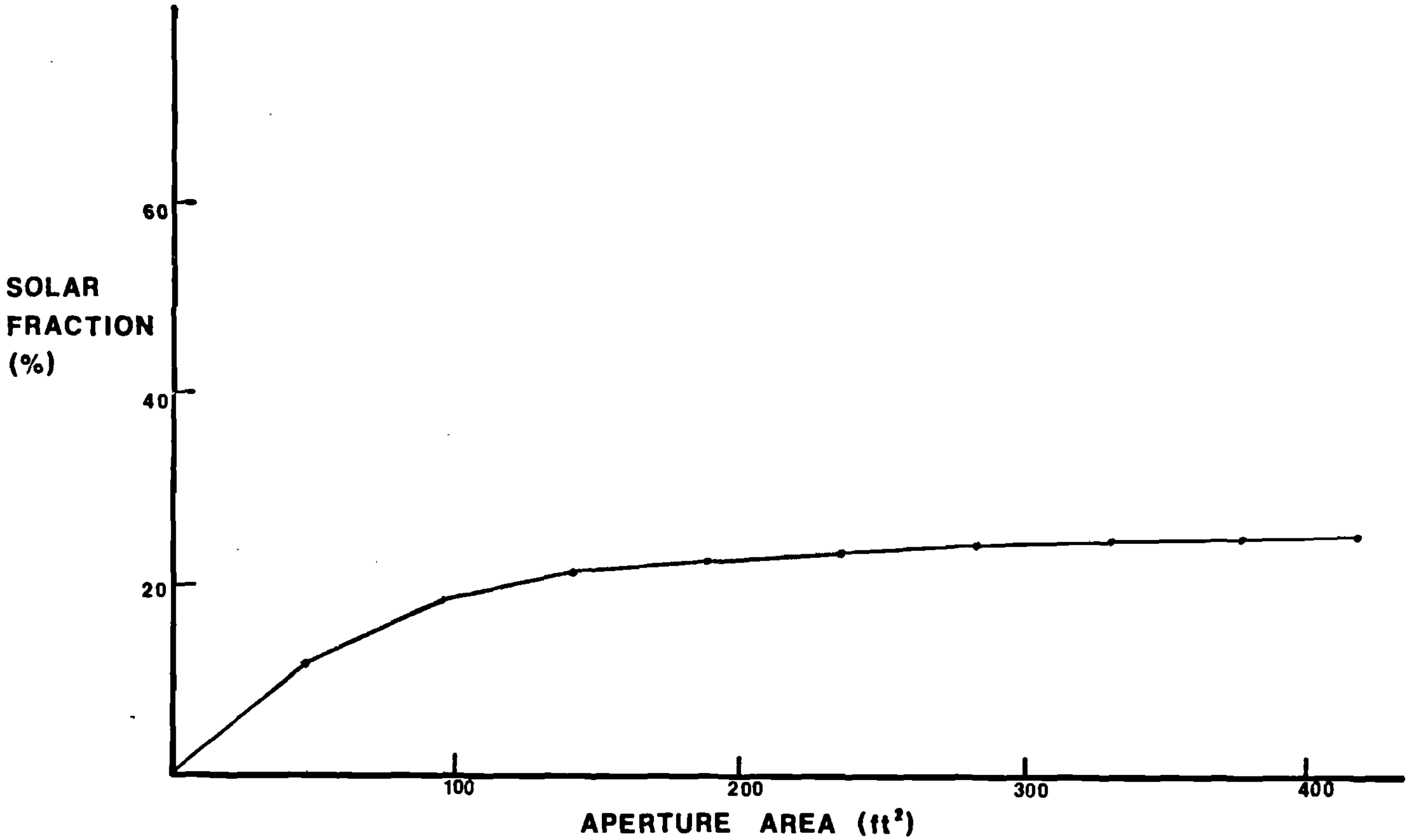


Figure 4 Direct Gain
PASSSY Simulation
For Typical January
15 Intervals Per Hour

glazed, the interior temperature rises to 81°F. With 90% (425 ft^2) glazed, the maximum interior temperature is 81°F. The solar fraction at 60% and 90% glazing is 24% and 25%, respectively.

Preliminary Costing and Economic Analysis

Preliminary costing was performed for the non-solar classroom building and each of the four passive design concepts. The price of the non-solar classroom building was estimated to be $39,850. This price is for the manufactured building erected on the site. It does not include the site preparation, concrete slab, electrical, or plumbing. The costs were figured for the passive techniques based on this non-solar building. Allowances were made for non-solar building costs that would not be incurred in the passive buildings (such as the cost of the conventional south wall). The resulting incremental price of each of the passive techniques is presented.

The cost for the direct gain system were based on a building with two-thirds of the south wall consisting of double-glazed, one-quarter-inch glass. The building has moveable insulation and some water, thermal storage. The incremental price for this building is estimated to be $6,650. A large portion of the extra cost is due to the glazing costs. The glazing costs can be reduced significantly by increasing the number of supports and decreasing the size of the individual glass panels. Using this alternate glazing scheme, the incremental price for this direct gain system would be about $4,257.

A simple economic analysis was performed for each of the four passive design concepts. The benefit/cost ratio was computed from the present values of the cash flows. The analyses are based on the following assumption:

1) the building is purchased by a local government, so there are no tax effects,

2) the customer's discount rate is 10%

3) the annual fuel escalation rate is 20%

4) the building life is 15 years,

5) the efficiency of the conventional heater is 70%, and

6) maintenance and operating costs for the passive system are negligable.

The fuel savings are based on annual simulations using PASSSY, with the non-solar building using 16.27 x 10^6 Btu/yr. Benefit/cost ratios were computed using both natural gas and Number 2 fuel oil for conventional heating. The current fuel prices were assumed to be $3.51/MBtu for natural gas and $5.49/MBtu for Number 2 fuel oil. The assumed discount and fuel escalation rates result in a present value of the fuel savings over the 15 year building life equal to 32.26 times the first year fuel savings. The incremental prices of the passive features were scaled linearly from the size for which the costing was done.

The economic analysis for the direct gain system was based on the lower cost, alternative glazing scheme. The resulting incremental system price is $12.61/ft^2. The benefit/cost ratios are presented below.

TABLE 3.
DIRECT GAIN BENEFIT/COST

APERTURE (FT^2)	NATURAL GAS	FUEL OIL
47.2	.50	.78
141.6	.31	.49
236.	.22	.34

These results are very sensitive to the economic assumptions. Changing from 15 years to 20 years approximately doubles the present value of the fuel savings and therefore, doubles the benefit/cost ratio.

5.2 Water Wall System

A modified direct gain system using water as a storage medium is another option for the school building. The water wall is a simple design, incorporating some direct gain of sunlight and heat into the classroom, while the remainder of the light falls on water storage containers which store and release the heat. The water storage system is compact, low cost, and is capable of storing large amounts of heat due to the superior heat capacity of water.

Building Construction

The basic classroom building will require little change to accommodate the water wall system. The double glazed south wall requires the normal overhang to shade the glazing during the summer months. The floor system may require a minor amount of strengthening to support the mass of water.

The water storage containers will be placed along the inside of the glazed south wall, allowing some light to enter the classroom while the remaining energy is stored. Water containers can also line the east and west walls of the classroom for a distance of approximately five feet. Several storage options exist. The simplest would be one gallon milk jugs filled with water, preferabley colored with dye. Self stacking heat storage containers are entering the solar hardware market. These are higher in cost, but may be more economical in the long run due to the elimination of shelving or other support systems. Large storage containers are also possible. Translucent fiberglass tubes holding 47 gallons of water (12" diameter x 8' tall) have been used successfully, as well as 30 gallon steel drums filled with water and a corrosion inhibitor.

The choice of storage container must address the possibility and results of vandalism. Plastic containers are easily punctured, while steel is much more immune to damage. Large and tall containers may tip over causing injury, hence they should be secured at the top. Smaller containers which can be replaced or repaired would minimize the impact of intentional or accidental damage.

System Operation

The water wall system allows fast response to changing conditions of heat load and sunlight. Insulating shutters would help the system but are not a necessity for buffering the classroom against exterior conditions.

As sunlight passes through the glazing, it strikes the water storage containers. These rise in temperature until they are hotter than the room and radiate and convect heat to the space. Water walls help eliminate overheating because of their ability to store heat quickly. This can cause problems, however, if too much mass is used as slow heating of the room during morning hours may result. Some heat would be stored and released at night when it is less needed.

System Viability

The water wall is more costly than a direct gain system. It provides more control over temperature swings and produces a more moderate temperature in the conditioned space. Large amounts of water are not needed as too much mass will cause slow heat up of the space during morning hours.

Performance Simulation

A computer simulation of heating load and solar system performance was conducted for the water wall system. Statistical weather and solar data were used for a typical winter. Figure 5 presents the solar fraction (percentage of total heat requirement supplied by solar) versus aperture area. The water wall will produce 50% of the heat required with 70% (330 ft^2) of the south wall glazed. Its greater ability to store heat than the direct gain system allows it to reach higher solar fractions.

Preliminary Costing and Economic Analysis

The costs for the water wall system were based on a building identical to the direct gain building, including moveable insulation. The thermal mass included in the direct gain building was subtracted and the cost of Kalwall water containers covering the entire glazed area was added. This is conservative since lower cost, used containers could be substituted. The incremental building price was estimated to be $8,600. Using the alternative glazing scheme the incremental price would be about $6,207.

The economic analysis for the water wall system was also based on the lower cost, alternative glazing scheme. The resulting incremental system price is $18.39/$ft^2$ of aperture. The benefit/cost ratios are presented below.

TABLE 4.
WATER WALL BENEFIT/COST

APERTURE (FT^2)	NATURAL GAS	FUEL OIL
47.2	.37	.58
141.6	.32	.50
236.	.28	.44

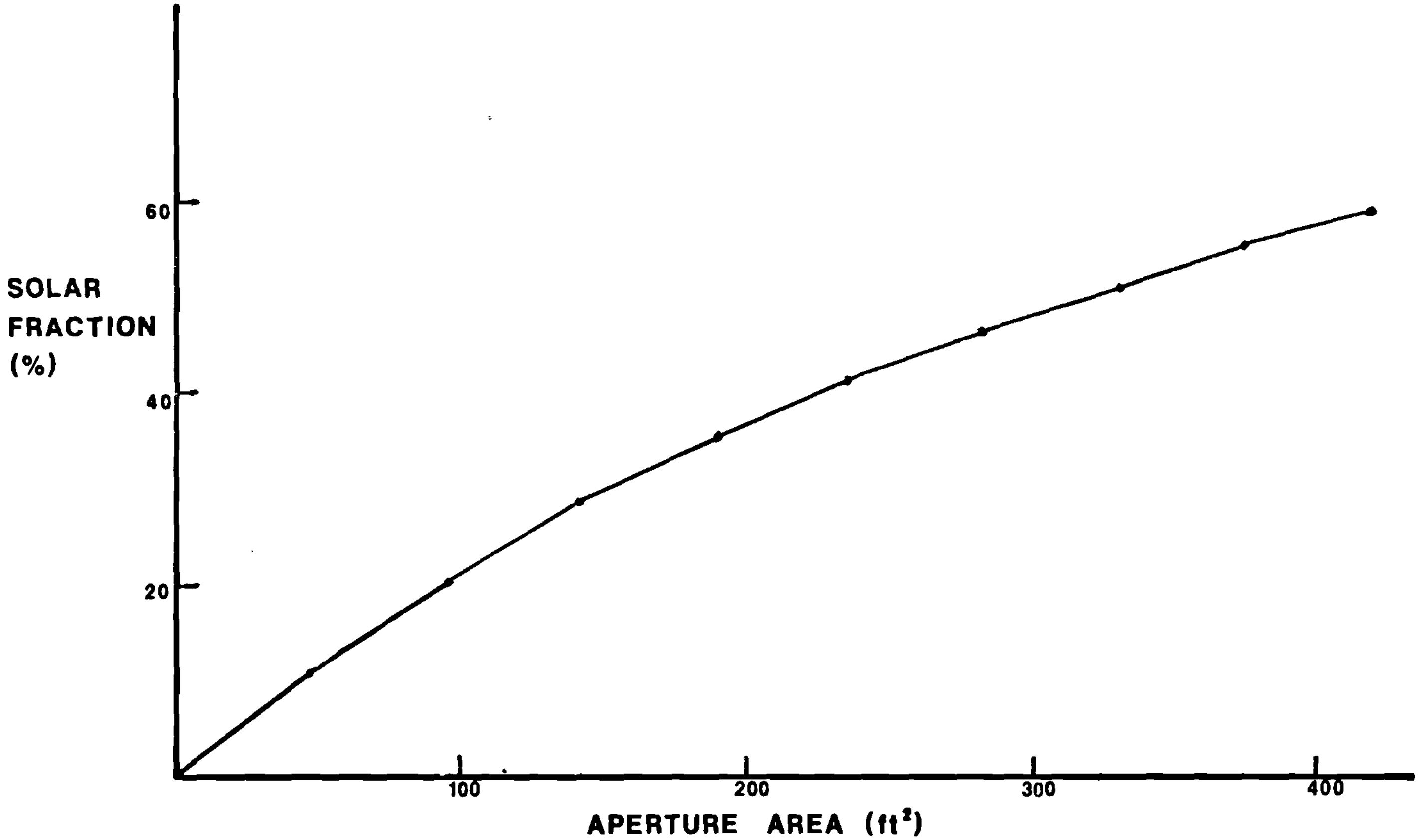


Figure 5 Water Wall System
PASSSY Simulation For
Typical January
15 Intervals Per Hour

5.3 Sunspace

Introduction

A sunspace or attached greenhouse is a building space receiving direct solar gain that is isolated from the normal living space of the building. The sunspace temperature is allowed to swing, while the living space temperature is controlled by alternately connecting and isolating it from the sunspace. This results in more moderate temperature swings in the living space than occur with a direct gain system. The trade-off is a resulting loss in efficiency of energy transfer to the living space.

There are a number of design parameters that affect the performance of a sunspace. These include the size, shape, and orientation of the sunspace; the number of glazings and the amount of night insulation; the amount of mass in the sunspace; the type of wall separating the sunspace from the building; and the method of heat transfer between the sunspace and the building. Each of these parameters was considered with respect to implementation and performance.

Building Construction

Several sunspace configurations were compared. The original sunspace concept included a sloped glass roof. This was later replaced by extending the conventional steel roof out to cover the sunspace. The larger aperture of the glass roofed sunspace was thought less important than the increased complexity and cost and the potential for summer overheating problems. Three types of wall construction were considered for the common wall between the sunspace and the classrooms; glass, poured-concrete, and conventional insulated. The conventional insulated wall with vents at the floor and ceiling is simple and low cost and provides good controllability. A glass wall allows direct solar gain by the living space. This reduces the controllability of the building and would probably necessitate moveable insulation. A concrete wall would also reduce the building controllability and would probably increase the total building heat load because of the lack of insulation on the solar wall. The construction costs of both the glass and concrete walls would be higher than the costs for a conventional wall.

Performance

Computer simulations were run on a classroom building incorporating a sunspace, using PASSSY. Simulations for the month of January were used for comparison. Initial runs were made to compare the performance of three types of common wall; conventional, glass, and concrete. These runs indicated that both the glass and concrete common walls perform slightly better than the conventional common wall. However, glass and concrete walls will cost more than the conventional wall. A series of runs were made to evaluate the fraction of the heating load that can be provided by a sunspace with a conventional common wall. The results of these runs are summarized in Figure 6. A sunspace one-half the length of the south wall provided approximately 27% of the required heating for January. A sunspace extending the entire length of the south wall provided approximately 33% of the required heating for January.

Preliminary Costing and Economic Analysis

The costs for the sunspace were based on a building with a sunspace running the entire length of the south wall. The

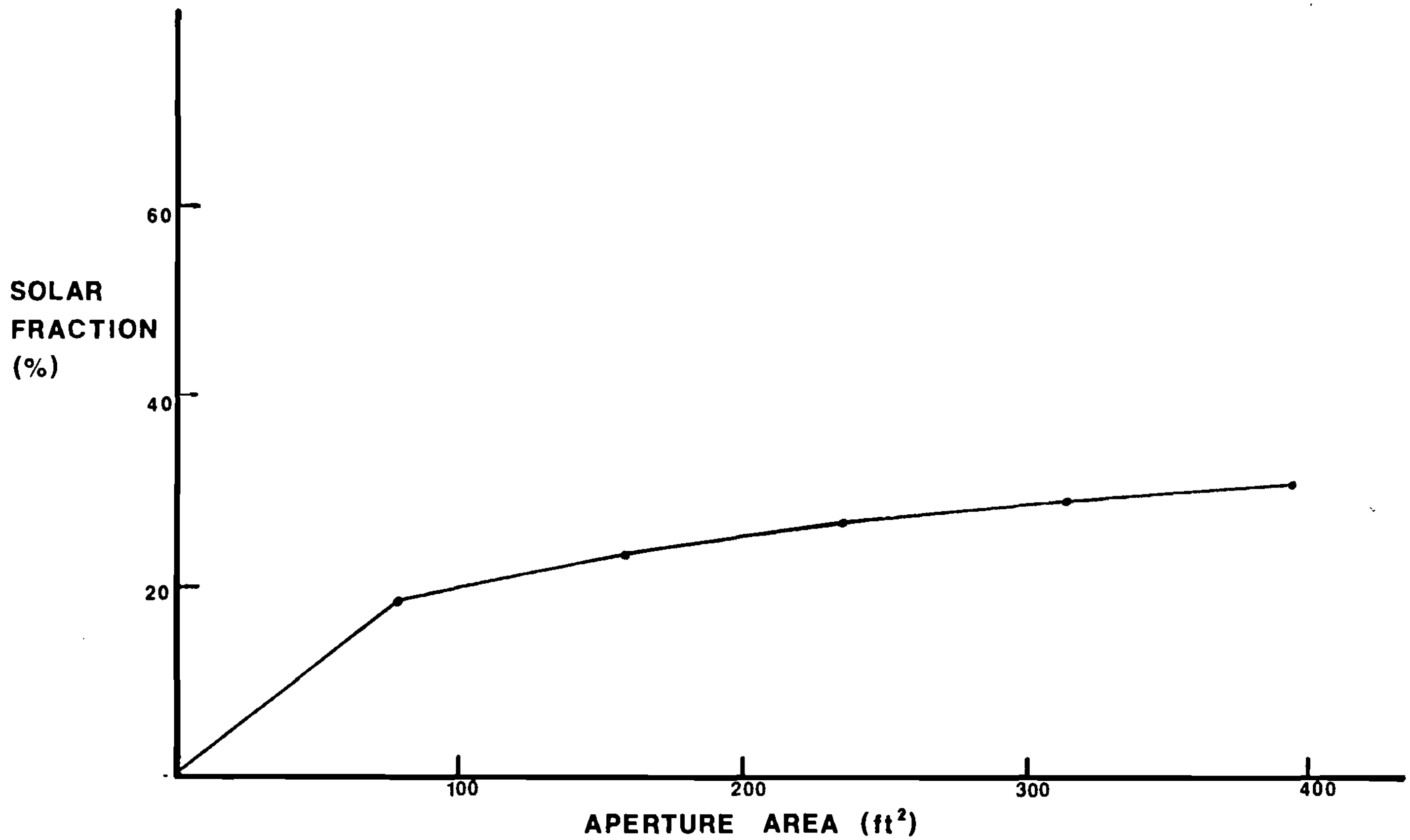


Figure 6 Sunspace System
PASSSY Simulation for
Typical January
15 Intervals Per Hour

entrance vestibules were moved to the south side of the building to make up a portion of the sunspace. The remaining portion of the sunspace is double-glazed glass. The cost of the additional 12-inch thick concrete slab was added to the incremental cost. The incremental price for the building with the sunspace was estimated to be $10,115. As with the direct gain building, the glazing is a major portion of this incremental cost. Using the alternative glazing scheme, the incremental price would be about $7,035.

The economic analysis for the sunspace was based on the lower cost, alternative glazing scheme. The resulting incremental price is $13.03/ft^2 of aperture. The benefit/cost ratios are presented below.

TABLE 5.
SUNSPACE BENEFIT/COST

APERTURE (FT^2)	NATURAL GAS	FUEL OIL
100.	.38	.59
200.	.25	.40
300.	.19	.30

5.4 Integral Collector Wall

Introduction

A simple natural convection collector based on the Mideck building panel was included in the passive design alternatives. This concept promises low unit cost, good performance, and easy control. In applications where passive-heating aperture is in excess of the code-mandated (10% of floor space) minimum fenestration; the integral collector wall is particularly suitable since it can provide heating without additional glare or noise. The integral collector wall is promising because it is inherently controlled against heat loss and does not require moveable insulation nor manual intervention in adjusting the insulation. An additional advantageous feature is that the integral collector wall is hardly less substantial than a conventional building panel and consequently does not degrade the fire safety or physical security of the structure.

Description

The integral collector wall, constituting a natural circulation loop, is constructed based on the conventional Mideck panel. The intended application is in a vertical wall; however, functional or architectural criteria may lead to future applications in sloped surfaces. The installation of the panel is reversed from the usual practice for walls in that the flanges are presented to the exterior (as is usual in roof construction).

General features of the collector panel construction are evident in the schematic cross-section of Figure 7. Glazing is supported by the panel flanges. Two glazings are shown as are indicated to be needed by preliminary analysis because of the strong dependence of collection efficiency on the top-loss coef-

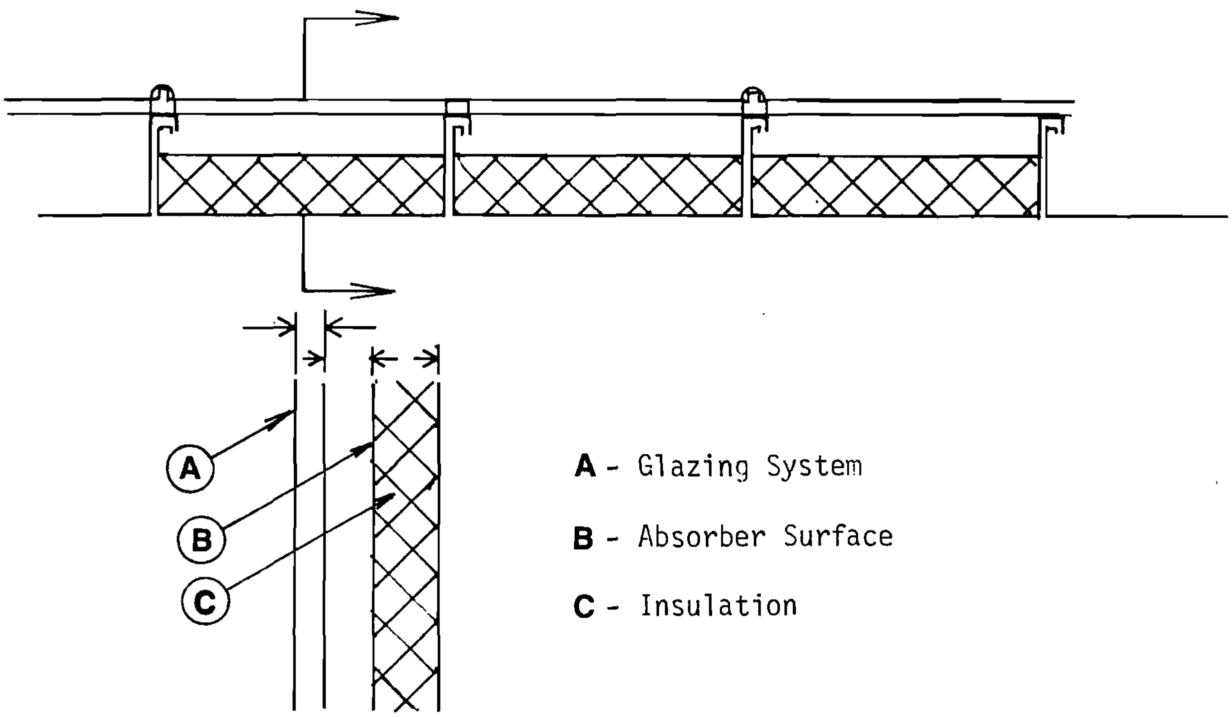
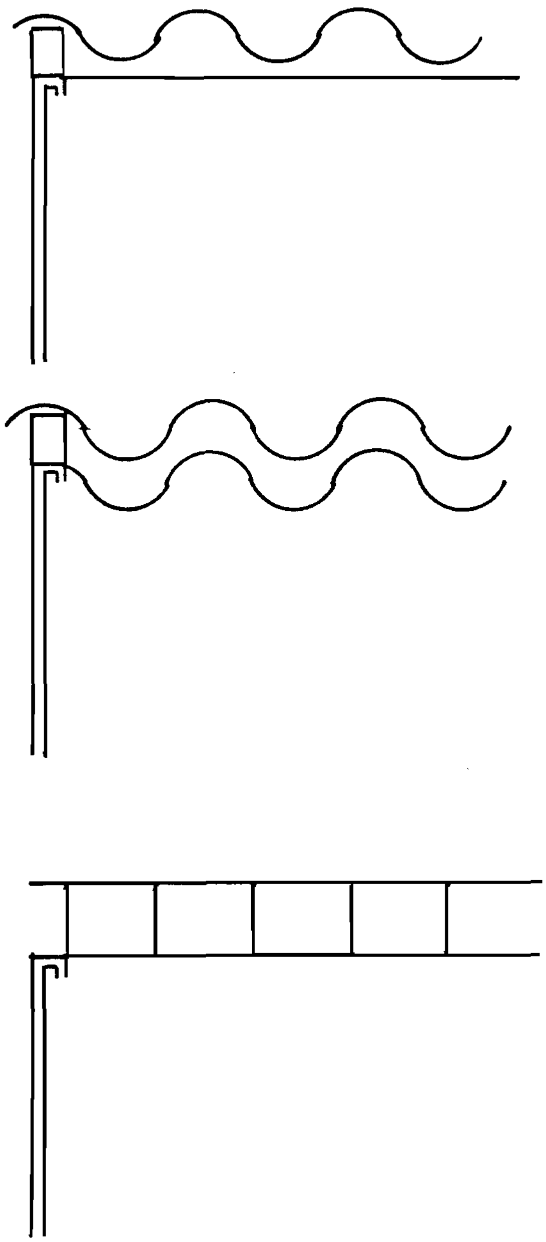


Figure 7 Schematic of Integrated Collector Wall

ficient for this arrangement of the flow passage. Inside the glazing is the rectangular duct for bouyant circulation of room air through the collector. The duct is formed by glazing on the outside and an insulating panel inside. The insulation forms a nearly adiabatic absorbing surface. This means quick heating of the conditioned space which is important in the initial design, a classroom without much nightime heating requirement. In future applications thermal mass (using latent heat materials for lightness) combined with insulation may be considered when nightime heating requirements are significant. In the present design, the outside surface of the insulation serves as the absorber.

Various arrangements of glazings are possible with this system. It is also felt that, since the glazing is separated from the occupied space by both the metal panel and the insulation, the fire danger to the occupants is not increased if polymer glazings are used. Some possible glazing configurations are shown in Figure 8. Either flat or corrugated glazings can be applied, but corrugated glazing might be preferred for its stiffness and appearance. Application of one of the newer extruded glazing might be considered for the benefit of a single-piece component that provides two layers without a spacer and quick, simple installation. It is felt that detailed costing of materials and labor requirements will dictate the selection of glazing material. Glass is durable and highly transmissive; however, the newer polymers for solar applications offer much easier installation along with good performance and acceptable durability.

Tests have been conducted at Georgia Tech using a simple fenestration calorimeter with an Epply Model PSP pyranometer as sensor to compare various candidate glazing materials. Results are summarized in Table 6. In the tests, the output of the PSP is measured when exposed directly to the sun and through a test



Corrugated fiberglass reinforced plastic outer glazing with plastic film inner glazing

Two corrugated fiberlgass reinforced plastic glazing

Extruded double-layer plastic glazing

Figure 8 Representative Glazing Systems

TABLE 6
COMPARISON OF GLAZING MATERIALS

Product Name	Description	Cost ($/ft^2)	Transmittance (%) Mfg. Data	Measured New	Measured Old
Kalwall Sunlite	Polyester-Glass Fiber Composit .040"	1.24	85-90	78.1	56.1
DuPont Teflon	Halogenated HC Film	0.26	96	95.5	
Martin Llumar	Weather Resistant Polyester Film .005"	0.27	88-90	84.4	
Filon #556	Acrylic-Polyester FRP	1.40	79	79.7	75.0
STC Acrylite SDP	Double-Skin Acrylic Sheet	1.30*	83	77.7	
ASG Sunadex	3/16" Tempered Glass .01% Fe	1.90	91.3	90.1	
ASG Solatex	3/16" Tempered Glass .04% Fe	1.43	89.1	88.2	
ASG Starlux	3/16" Tempered Glass		82	81.8	

*1/2 cost of double-glazed product

sample of glazing. Masks allow the use of larger apertures until it is clear that the scattered component of the transmitted radiation is fully accounted for. The ratio of the measured output voltages represents the transmittance. This test does not depend on the absolute accuracy of the PSP, only its linearity. Furthermore, it is a simple and direct test not dependent on numerical integration over an assumed spectrum. Several glazing methods appear promising such as glass outside with an inner layer of Teflon (or other film), double glass, and double FRP. Actual quotes and manufacturing implications will determine the cost/benefit ratio and final glazing selection.

The insulating panel also acts as the absorber. A foam insulation is preferred for its impermeability (at least in the initial applications). Foam glass is the preferred material since it is non-combustible, waterproof, and durable. Other candidate materials include the urethane foams and polystyrene foam. These materials are less expensive than foam glass; however, both are potentially flamable and subject to thermal degradation and break-down by solar irradiation. Foam glass is a conservative materials choice because of its performance and durability. A potential future material could be glass fiber; however, problems from condensation are foreseen. The absorber will be coated with a recommended flat black enamel. The inherent dark color of foamglass should mitigate against loss of absorption from limited paint peeling.

The insulation should be of economical thickness to prevent uncontrolled heat gain as well as retard heat loss during sunless periods. A two-inch layer of foamglass provides about R-10 insulation (including air gap and glazing system) while allowing sufficient duct area for the bouyant flow. If required as in severe winter areas, inexpensive beadboard insulation could be applied to the inside of the metal panel.

The remaining aspect of the collector panels is the ventilation system. As shown in Drawing A3, vents are provided to let room air into the bottom of the collector panel, to supply heated air to the room, and during the warm season, exhaust heated air to the outside. Analysis shows that dynamic losses at the inlets and outlets dominate the overall pressure drop in comparison with the frictional resistance. This indicates the necessity for care in implementation of the vents to avoid unnecessary expansion or contraction of the duct and to allow smooth transition and direction of the flow from the still room air to the bouyantly-convected air in the duct. Closely spaced louvers appear to be most practical for application to the interior vents. The lip of the inlet (lower) louver should be directed downward and into the room. This provides for smooth flow without unnecessary rotation and also gives a flat surface for the back-draft damper film to seat against. The inverse arrangement should be applied at the outlet (upper) louver. An external vent is installed in the exterior paneling just above the glazing. A system of matched perforations that can be slid into alignment to open or staggered to closed seems simplest. An optional inside rigid damper is provided to deactivate the collector wall during the warm season. Use of this damper should be restricted to times when the external vent is opened to preclude stagnation in the collector (especially when polymer glazing is used). Occasional overheating can be compensated by ventilating the room, or the two rigid dampers can be made to act cooperatively.

Performance

A form of the Hottel-Whillier-Bliss collector model based on the average collector temperature was used in the performance simulations. This allows rapid simulations by avoiding detailed fluid dynamics calculations. When experimental performance data for the integrated collector becomes available, the program will be modified as required.

Analytical results indicate that entry and exit momentum effects which are difficult to estimate dominate the dynamics of the air flow. Using standard methods, a temperature rise of 15°F through the collector wall is estimated for design conditions. This corresponds to a regime of flow near the turbulent transition but likely to be laminar at most times. The convection coefficients between the absorber and the air were thus based on a Nusselt number of 4.4, and the same value was assumed between air and cover. An overall loss coefficient for the cover was calculated using Klein's formula.

Formulae presented by Duffie and Beckman allow the calculation of the collector efficiency factor and effective collector loss coefficient for this collector design. The efficiency factors for single and double glazing are:

single glazing	0.56
double glazing	0.77

The strong dependence of F' on the collector top loss indicates that double glazing is preferred. This is as expected since the heated air contacts the cover system directly. For double glazing an overall loss coefficient of 1.71 Btu/hr/ft^2/F° was calculated.

When the collector ceases to produce a net heat gain, bouyant convection stops and the backdrop dampers prevent flow in the duct. Thermal performance during such periods is calculated by assuming the collector to perform as an insulated wall with conductance of 0.097 (R-10). This should be conservative as some heat might still be absorbed to raise the temperature of the absorber surface above that found during pure conductive loss.

Since it is expected that the integral collector would never constitute the entire solar wall (some water wall or direct gain aperture would be used for daylighting at least), annual simulations were performed with nominal amounts of the other systems included. Results are summarized in Table 7.

TABLE 7.
AUXILIARY HEATING WITH INTEGRAL COLLECTOR WALL

Solar Wall (%)			Aux Heat (10^6Btu/yr)
Direct Gain	Water Wall	Integral Collector Wall	
DG	WW	ICW	
10	10	10	11.91
10	10	30	10.97
10	10	50	10.54
10	10	70	10.32
0	0	0	16.20

Simulations were also performed for January on a building incorporating only the integral collector wall. These results are presented in Figure 9.

Preliminary Costing and Economic Analysis

The costs for the integral collector wall were based on a building with integral collector along the entire south wall. The collector is glazed with two layers of Vistron Filon fiberglass glazing. Pittsburg Corning Foamglas is used for the insulation. The incremental price for this building is $2,175.

The economic analysis for the integral collector wall is based on an incremental price of $4.53/ft^2 of aperture. The resulting benefit/cost ratios are presented in Table 8.

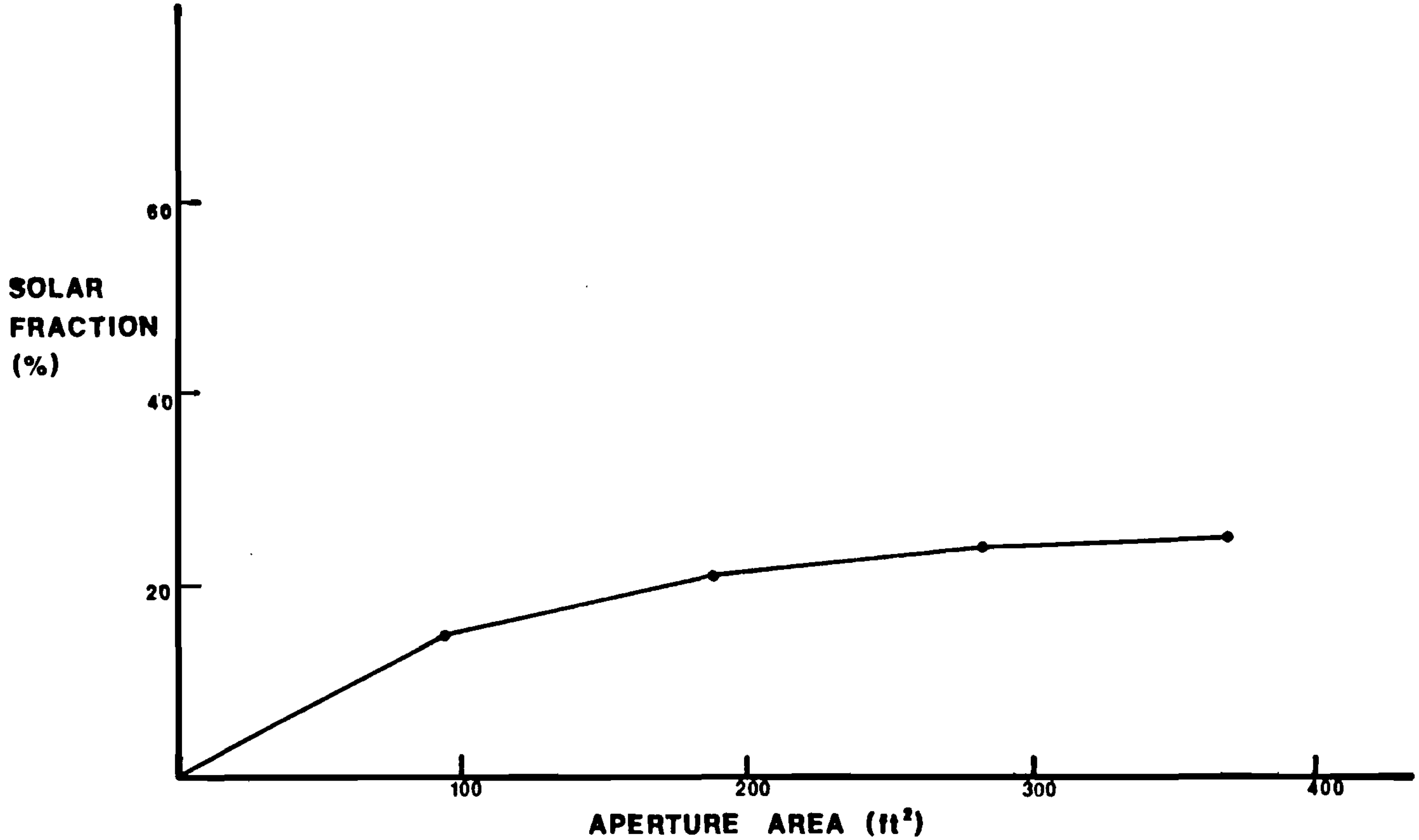


Figure 9 Integral Collector Wall
PASSSY SIMULATION FOR TYPICAL JANUARY
15 INTERVALS PER HOUR

TABLE 8.
INTEGRAL COLLECTOR WALL BENEFIT/COST

APERTURE (FT^2)	NATURAL GAS	FUEL OIL
47.2	1.15	1.79
141.6	.81	1.26
236.	.61	.95

5.5 Daylighting

Daylighting is receiving increasing amounts of attention as a method of reducing energy consumption in various types of buildings. A literature search was performed to learn the important concerns for daylighting for this classroom application and to assess the available daylighting design applications. Commercial buildings are especially attractive for daylighting because they are used primarily during the daylight hours and also because the substitution of natural light for artificial light can result in a reduction of the buildings cooling load.[8] Daylighting design should address a number of considerations including control of the natural light, especially direct sunlight; the thermal impact of the daylight; and provisions for controlling the artificial light input to the space.

The Windows and Daylighting Group of the Lawrence Berkeley Laboratory (LBL) is involved in research into a number of aspects of daylighting design. In a discussion of daylighting, Richard Johnson of LBL expressed a number of important concerns for a passive solar heated building design that incorporates daylighting. He emphasized the importance of the thermal design of the building, especially overheating concerns. The building should be comfortable during the cooling season and should require no mechanical heating or cooling on days with pleasant outdoor temperature and relative humidity. This can be achieved through proper shading and adequate cross ventilation. Mr. Johnson discussed the quality of natural light, indicating that diffuse skylight is preferable to direct sunlight and that ideally lighting should come from the side. He also discussed several available daylighting analysis techiques and available daylighting design data. He said that currently, the best daylighting tool is a three dimensional model of the building.[9] This method was used in the daylighting analysis of the classroom building. The results of this analysis are discussed later in this report.

References 8, 10, 11, 12 and 13 give a good overview of the important concerns in daylighting design. Stephen Selkowitz of LBL emphasized benefits to be derived from daylighting in addition to reduced energy consumption. These include the reduction in peak power demand; independence from artificial lighting and mechanical heating, cooling, and ventilation which can allow utilization of the space during power outages; and improvement in the quality of light and therefore the working environment.[8] The last two concerns are important to the classroom application.

In order to derive energy savings from daylighting, artificial lighting must be reduced. This can be achieved by manual control of the artificial lighting. In some instances it may be preferable to utilize automatic on/off or dimming control of artificial lighting. Equipment is now on the market to switch or dim flourescent fixtures automatically. Much of this equipment is relatively new and little operating experience is available at this time. A number of manufacturers have been contacted about lighting control equipment. At least one manufacturer has indicated that they have equipment appropriate for this specific application. They have also expressed an interest in being invovled with this program.

6. FINAL DESIGN

6.1 Specifications

The final design for the prototype classroom building incorporates all four passive solar heating concepts. The south wall will consist of approximately one-third integral collector wall and one-third glazing. About one-half of the glazing will be taken up by water containers. A horizontal light shelf will be located above the water containers to help control direct sunlight. A portion of the south glazing will be operable and operable north glazing will be provided for cross ventilating the classrooms. The entrance vestibules will be located at the south corner of the east and west walls where they will serve as attached sunspaces. A complete set of drawings of the prototype building has been submitted to the program sponsor.

A summary of the passive solar components for space heating is provided in Table 9.

6.2 Conservation Features

In addition to the passive solar components, several conservation details were included in the final design. These features should enhance the overall energy performance of the building by reducing the heating or cooling loads, providing for natural cross ventilation, and providing economical energy for hot water.

To reduce the space conditioning load caused by heat diffusion the final design includes a thicker batt of ceiling insulation and construction over a slab floor. The preliminary design included a standard 6" ceiling batt and a floor over an air space. A 12" ceiling batt in conformance with contemporary practice is now included. Furthermore, a slab floor with perimeter insulation substantially reduces the heat gain (or

TABLE 9

FINAL DESIGN SPECIFICATIONS SUMMARY

Component	Percent of South Wall	Area (sq.ft)
Integral Collector	33.33%	175.7
Water Wall (with light shelf)	26.55%	140.0
Direct Gain	6.78%	35.7
Total	66.66%	351.4*
Aperture/Integral Collector	33.33%	175.7
Water Wall	18.03%	95.0
Direct Gain**	15.30%	80.7
Total	66.66%	351.4

*18% of occupied floor space

**includes DG above WW

loss) while providing additional thermal capacitance. These alterations result in a reduction of the overall building conductance (heat transfer exclusive of infiltration or ventilation) from a basic value of 306 Btu/(hrF°), for the non-solar envelope exclusive of conventional windows, to a value of 238.6 Btu/(hrF°). Additional insulation in the non-solar walls was defered because of expected problems in altering the standard construction techniques at Madison Industries. The slab floor is also expected to enhance customer acceptance of the classrooms. For Atlanta's normal 2,397 heating degree-days these modifications indicate a net savings of 3.88 million Btu's per year.

A substantial portion of the space-heating results from outside air introduced by infiltration or required ventilation. It is possible to achieve an infiltration rate of no more than 1 ACH which represents a volumeteric flow of 15,900 ft^3/hr implying a heat loss rate of 290 Btu/(hrF°). The local code, however, requires a ventilation of 7.5 SCFM per person for classrooms. It would be unproductive to expend excessive effort to reduce infiltration so long as the ventilation of 22,500 ft^3/hr is required since the only positive benefits would be a possible reduction in draftiness and an increased COP for a heat pump if used. It seems most reasonable to reduce the heat loss by introducing the excess required ventilation air by means of an air-to-air heat exchanger. This can be accomplished by installation of a packaged heat exchanger such as the Mitsubishi Lossnay LGF-40. This commercial-duty total-enthalpy exchanger has a heat-exchange effectiveness of 75% at the anticipated flow rate. This installation serves two purposed in winter:

a) reduces sensible heat load
b) enhances indoor relative humidity

If the classroom is cooled for summer-quarter use, the Lossnay is effective in reducing the total cooling demand (latent and sensible heat).

6.3 Thermal Performance

A final computer simulation was run for the prototype building and the non-solar building using Version 10 of PASSSY. This version incorporates additional insulation in the ceiling, slab floor construction, and a ventilation heat recovery unit. The results of these runs are summarized in Table 10. The annual simulation predicts that the passive solar prototype building will use approximately 45% less auxiliary heating energy than a similar non-solar building.

TABLE 10

FINAL DESIGN SIMULATION RESULTS

	AUXILIARY HEATING REQUIRED		
MONTH	PASSIVE SOLAR BUILDING (BTU)	NON-SOLAR BUILDING (BTU)	REDUCTION (%)
January	1,575,951	2,766,151	43
February	2,251,403	3,829,485	41
March	1,876,349	3,163,098	41
April	234,309	339,898	31
May	20,735	29,973	31
June	0	0	-
July	0	0	-
August	0	0	-
September	10,713	46,072	77
October	191,594	539,585	64
November	1,211,262	2,328,110	48
December	1,392,207	2,843,527	51
Total Annual	8,764,524	15,885,899	45

6.4 Sensitivity Analysis

To access the adequacy of the final design, a sensitivity study was conducted by comparing the final design with alternatives using slightly larger and slightly smaller solar walls. The results of this study are summarized in Table 11. It is seen that an incrase in solar wall aperture of 10% increases the solar reduction of heating load by only 4% while decreasing the solar wall aperture by 10% decreases the solar participation by 5%. This indicates that the selected solar wall aperture (2/3 of the south wall) is within bounds if a reasonable design as it is beyond the point of disproportionate contribution but not so large as to approach the area where the marginal contribution of an increase in aperture diminishes to an insignificant level.

TABLE 11

RESULTS OF SENSITIVITY ANALYSIS

Component of Solar Aperture	Final Design	Percentage of South Wall Final Design + 10%	Final Design - 10%
Integral Collector	33.33	36.66	30.00
Water Wall	18.03	19.83	16.23
Direct Gain**	15.30	16.83	13.77
North Window Area (ft^2)	59	59	59
Annual Heat Load (10^6 Btu)	8.764	8.453	9.113
% Final Design	100%	96%	104%
Reduction in Heat Load (10^6 Btu)	7.122	7.433	6.773
% Final Design	100%	104%	95%

6.5 Orientation Studies

As expected for a building having a drastic nighttime temperature setback during unoccupied evening and nighttime periods and a relatively large internal generation of heat during the school day, the modular classroom demonstrates a significant peak in heating requirements during the earliest morning hours.

A preliminary numerical investigation was conducted to determine if this asymmetry in the heat demand would dictate a siting constraint that favored exposure to the morning sun. Our results indicate a slight enhancement in performance for small eastward orientation of the solar wall; however, the gain is so small that while such an opportunity should be exploited if convenient there is no basis for a restrictive siting requirement. Typical results are shown in Table 12. These preliminary results are for typical January weather and solar resources and are generated by the program PASSSY without any special modifications since a general orientation is provided for inherently.

TABLE 12

EFFECT OF SOLAR WALL ORIENTATION ON AUXILIARY HEAT

Solar Wall (%) DG	WW	ICW	Azimuth of Solar Wall	Auxiliary Heat Req'd. (10^3Btu)	% Base Case
0	0	0	0	2,832	160
20	20	20	0	1,771	100
20	20	20	10	1,757	99
20	20	20	25	1,781	101
20	20	20	45	1,885	106

6.6 Daylighting Modeling

Some techniques exist to assist in the design of fenestration and other architectural features for the utilization of natural daylighting; however, the assessment of annual daylighting performance for a given design represents a distinct problem. To accomplish this assessment a procedure was developed based on an efficient combination of empirical and numerical techniques which allow the estimation of the annual contribution of natural daylighting to the illumination requirements of the subject building design.

The empirical basis of the procedure was provided by a series of measurements using a scale model of the shown in Figure 10. The model was mounted in a manner to allow both inclination and rotation so that a variety of solar exposure angles could be investigated. A pyranometer was mounted parallel to the solar wall to provide data on incident radiation.

Access holes through the model base provided a means for inserting a commercial photometer to measure light levels at the scale height of the classroom desks. Figure 11 shows the interior view of the model and one of the holes for the photometer. Light measurements for each observation were made at three representative locations in the classroom areas - at the center, at the center of the southerly half, and at the center of the northerly half of the building.

The contribution of beam radiation is of primary interest; therefore, measurements were made for various solar profile angles relative to the solar wall. The profile angle is the solar altitude projected into the cross-section plane of the building. Because the solar wall is relatively long (8'10" by 59'8"), the distribution of transmitted irradiance is primarily two-dimensional. This simplification reduces the problem of conducting the observations. Illumination readings were taken by

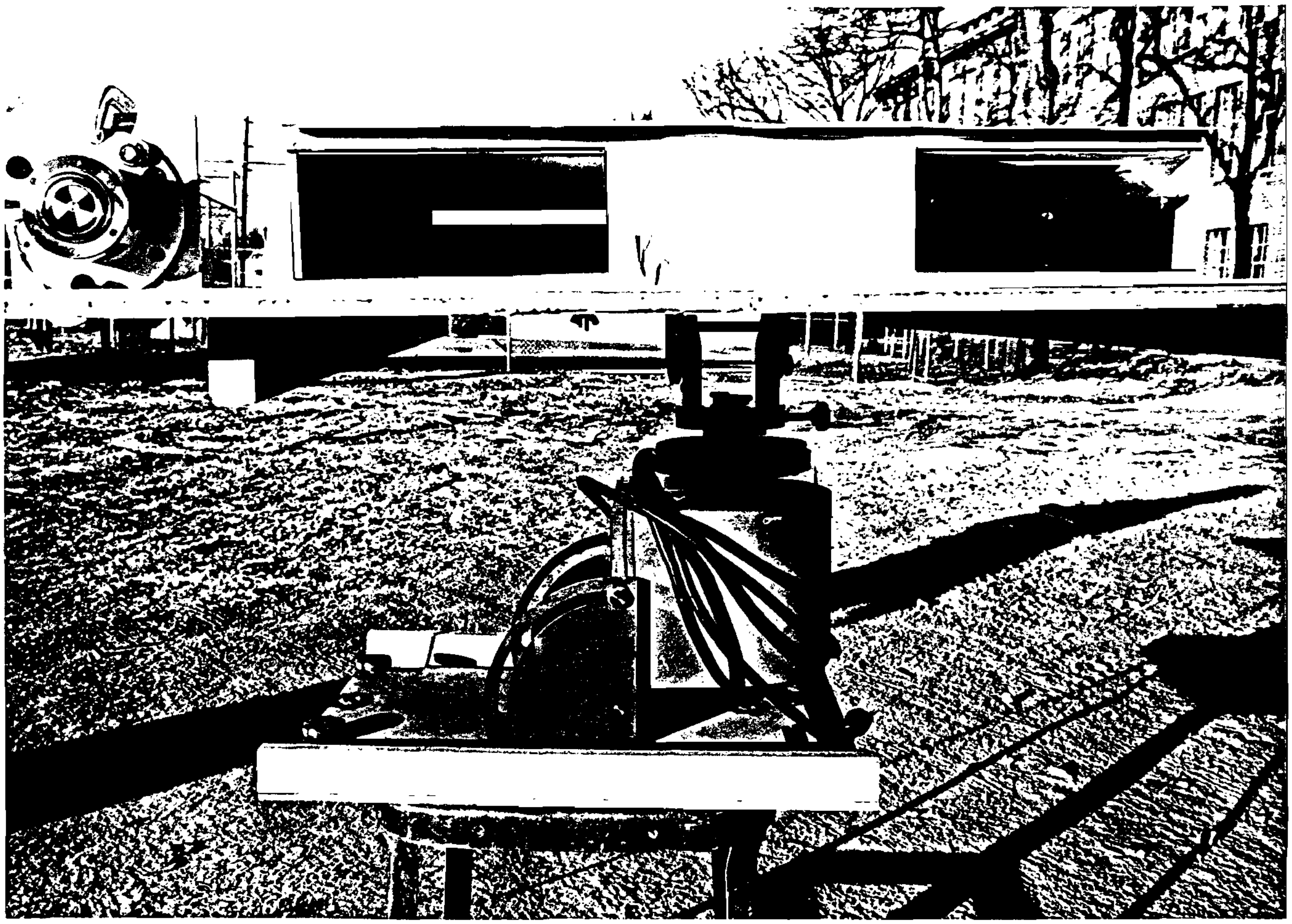


Figure 10 Scale Model of Classroom Building

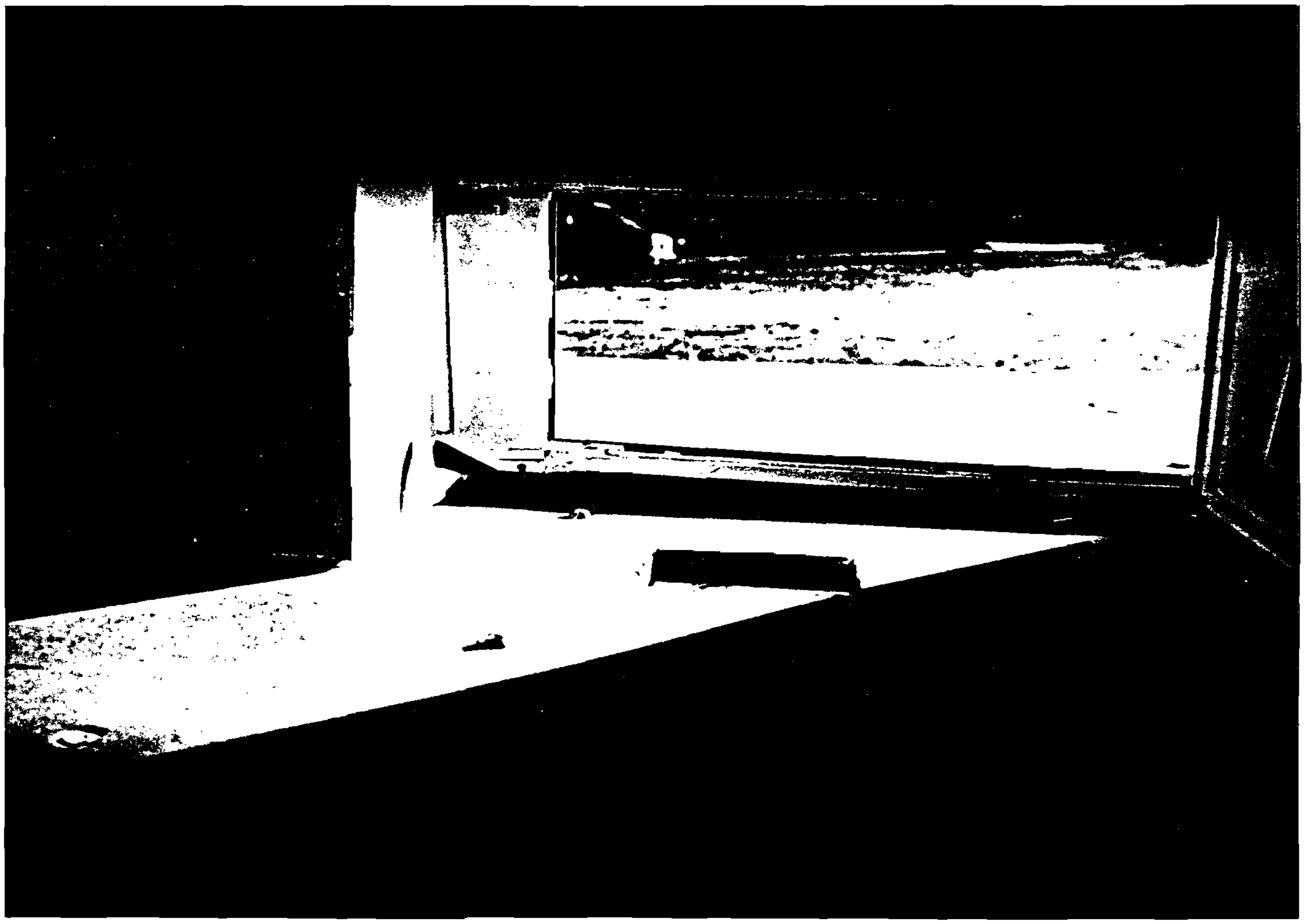


Figure 11 Inside View of Building Model

pointing the building toward the sun and tilting it to simulate various profile angles. Readings were taken in footcandles at work height inside the model (with representative fenestration in place) simultaneously with readings of the incident irradiation on the solar wall. Figure 12 shows the model with a simulated water wall and light shelf in place.

Readings were taken under both clear sky and overcast conditions. The results for each room location were summarized as the ratio of indoor illumination to incident irradiation. For direct illumination, this ratio should approximate a function of the profile angle, ψ,:

$$f(\Psi) = \frac{\text{Indoor Illumination (footcandles)}}{\text{Exterior Irradiation } (\text{Btu}/(\text{hrft}^2)}$$

Graphs of these data were prepared and are presented in Appendix A, for both the direct gain configuration and a six foot water wall with a light shelf.

In order to interpret these data in a simulation for the actual classroom, total illumination at a location in the room was taken to be the sum of direct and diffuse components which are proportional respectively to the direct and diffuse insolation components on the solar wall. These insolation components were provided by the SOLMET data tapes and used to compute the lighting distribution.

Assuming the geometrical distribution of direct illumination is determined by $f(\psi)$ it remained necessary to estimate the illumination for a given incident angle which is different from that of the test. If the transmittance of the fenestration is T, then:

$$\text{Direct Illumination} = f(\Psi)\,\frac{T(\theta)}{T(\Psi)}\quad\text{(Direct Irradiation)}$$

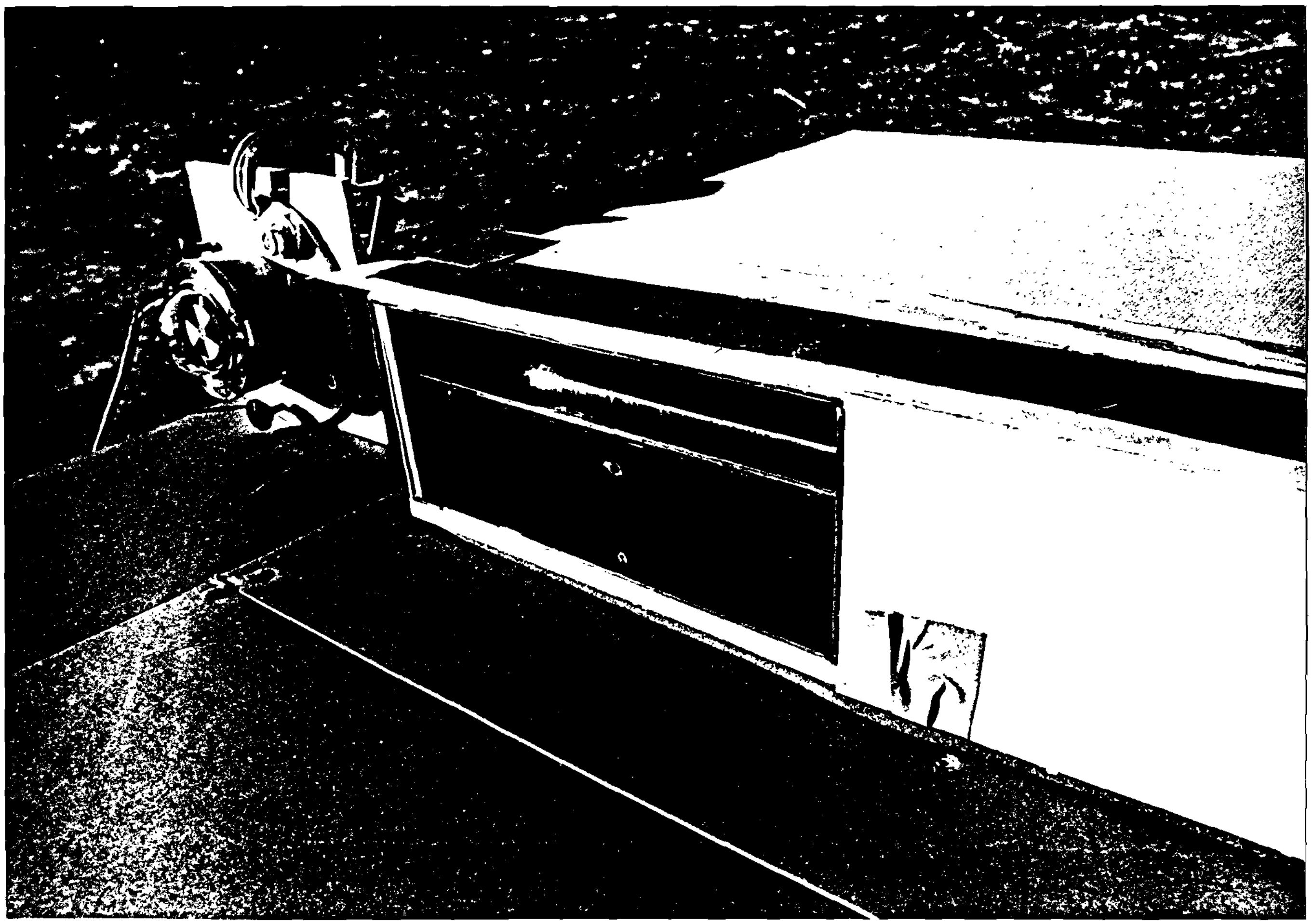


Figure 12 Classroom with Water Wall and Light Shelf

where θ is the current angle of interest.

Since a combination of passive solar features is included in the final design, each will contribute to daylighting. The total illumination was computed as the sum of the illuminations from each technique, weighted according to its proportion of the solar wall. This sum was then compared with the design illumination level. The percentage of necessary illumination provided by natural light can be calculated for each (hourly) period for which solar irradiance data is available.

Version 10 of PASSSY was modified to do this daylighting calculation. The lighting level was calculated once an hour at each of the three positions in the classroom. The building was credited with 1/3 hour of daylighting if the illumination level at a position was greater than 70 footcandles. The results of the daylighting simulation are shown in Table 13.

TABLE 13
DAYLIGHTING SIMULATION RESULTS

MONTH	HOURS OF DAYLIGHTING
January	41
February	38
March	37
April	24
May	14
June	--
July	--
August	--
September	11
October	27
November	44
December	50

7. PRELIMINARY MARKET ANALYSIS

A substantial market exists for additional school classrooms throughout the country both in school districts with expanding or shifting enrollments and in districts with stationary populations needing to replace decaying facilities. The passive solar manufactured building wil be offered to school districts experiencing rapid growth where overcrowding has intensified the need for new buildings. This growth is often unanticipated making the solar manufactured building, whether panalized or modular, an attractive option for meeting strong and unexpected increases in enrollment. Two general situations generate demand for this building:

(1) Rapid regional growth (e.g., Hillsborough County, Florida)

(2) Moduate regional growth with population shift to suburban localities (e.g., Gwinnett County, Georgia)

The generally anticipated population increase in the southeast created both by net immigration from other regions and the relatively high birth rate in the region will sustain the market for manufactured classrooms. This growth should persist regionally despite the tendency for the school-aged population to moduate and decline nationally. Additionally, the market depends rather more on growth which can be called unanticipated (i.e., increased enrollment in districts where planning has been inadequate or new construction deferred in spite of recognized need) or unexpected (i.e., increased enrollment in districts faced with sudden growth or redistribution of the population). Consequently, the contemporary uncertainty with regard to future population patterns and the current reluctance to expand conventional educational facilities should favor the introduction of manufactured buildings. For example, a decline or reverse in regional migration to the suburbs in the face of mounting expenses for commuting and for conditioning the detached single-family home will result in current school construction being misplaced. Another example could be the development of a strong and immediate need for classrooms in a county where capital expenditures have been deferred to encourage growth by minimizing local taxes. Once growth is experienced the need for school facilities will be accentuated.

Marketing of the passive solar manufactured building will be in three phases:

1. Sale to an Atlanta area school district of the prototype building under Phase II of this program. Ideally, this sale will be coordinated with the sale of conventional classroom for similar usage to provide a direct comparison of energy costs.

2. Sales of the passive classrooms in north-central Georgia. This will facilitate controlled increases in production and quality control throughout manufacture and installation. The prototype could have been occupied under similar climatic conditions which enhances the promotional value of the prototype experiences.

3. Sales of passive classrooms, optimized for local conditions throughout the southeast. Since the passive classroom emphasizes conservation and controlled heat-gains, it is suitable for sale throughout the temperate southeast. Experience will provide the needed basis for locally-acceptable designs.

The potential market can be roughly estimated with reference to the following table. From the U.S. Statistical Abstract it is seen that elementary and secondary school students constitute about 22% of the regional and 23% of the state population. Using the growth estimates from a recent report by the Atlanta Regional Commission results in the indicated raw demand for classroom space (assuming 25 students per room). It is notable that the expected growth in the Atlanta metropolitan region exceeds the statewide growth (owing to intrastate migration). Since adequate well-located facilities are currently needed in the Atlanta region, the potential local demand for manufactured classrooms is apparent.

It is obvious that even a small impact in this large potential market (604 classrooms annually in the Atlanta region alone) will sustain a large manufacturing effort and greatly enhance the visibility, familarity, and public-acceptance of passive buildings.

TABLE 14

POTENTIAL MARKET ESTIMATES

	School Age Population(1) (1000's)	Total Population(1) (1000's)	Percentage
South Atlantic	7,633	33,990	22
Georgia	1,154	4,970	23
	Population Growth (1000's) (2)		
	1980-1990	1990-2000	
Southeast (3)	2,902	N/A	
Georgia	570	N/A	
Atlanta Region	695.9	791.3	
	Classroom Demand (4)		
Southeast	25,540	N/A	
Georgia	5,240	N/A	
Atlanta Region	6,400	7,280	

(1) Source: U.S. Statistical Abstract, data for 1976.

(2) Source: Atlanta Regional Commission, "Population and Housing," 1976.

(3) Includes: FLA, GA, MS, NC, SC, TENN, ALA.

(4) Assumes 25 students/classroom.

REFERENCES

1. Klein, S.A., W. A. Beckman, et al, "TRNSYS, A Transient System Simulation Program," Engineering Experiment Station Report 38, University of Wisconsin - Madison, June, 1979.

2. Liu, B.Y.H., and R.C. Jordan, "The Long-Term Performance of Flat-Plate Solar-Energy Collectors," Solar Energy, Vol. 7, No. 3, 1963.

3. Klein, S.A., "Calculation of Flat-Plate Collector Utilizability," Solar Energy, Vol. 21, pp 393-402, 1978.

4. Klein, S.A., W. A. Beckman, and J.A. Duffie, "A Design Procedure for Solar Heating Systems," Solar Energy Vol. 18, pp 113-127, 1976.

5. Balcomb, J.D., et al, "Passive System Design Handbook, Volume Two: Passive Solar Design Analysis," DOE/CS-0127/2, January 1980.

6. "Passive FCHART: Version 0.9, Users Manual," NESEC Technical Report #7, 24 October 1979.

7. Arumi-Noe, F., "A Model for the DEROB/PASOLE System," Proceedings of the Second National Passive Solar Conference, p. 529, 1978.

8. Stephen Selkowitz and Richard Johnson, "The Daylighting Solution," Solar Age, August 1980.

9. Telephone Conversation with Richard Johnson of Lawrence Berkeley Laboratory, Windows and Daylighting Group on August 20, 1980.

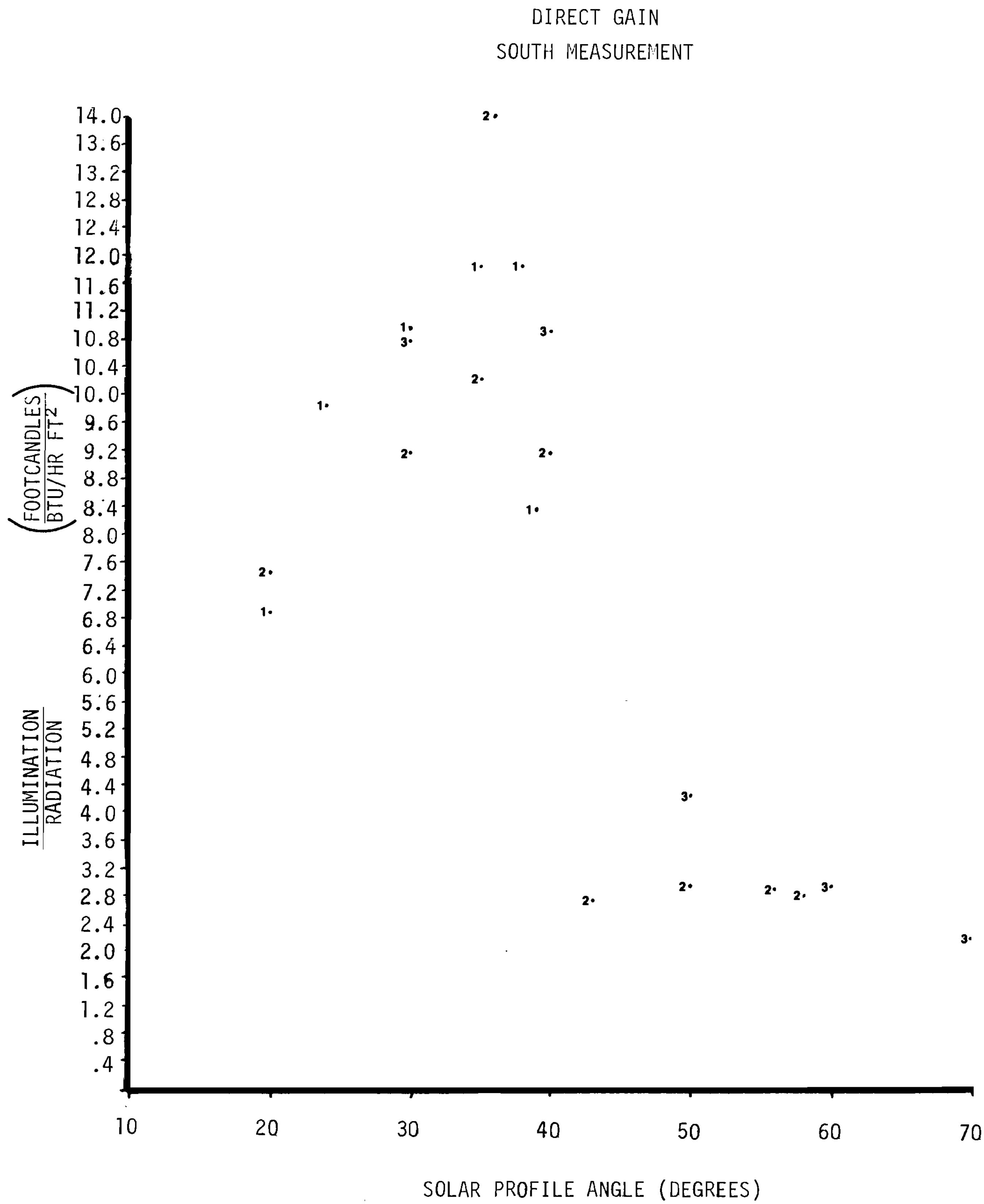
10. Stephen Selkowitz, "Effective Daylighting in Buildings - Part 1," Lighting Design & Application, February 1979.

11. Stephen Selkowitz, "Effective Daylighting in Buildings - Part 2," Lighting Design & Application, February 1979.

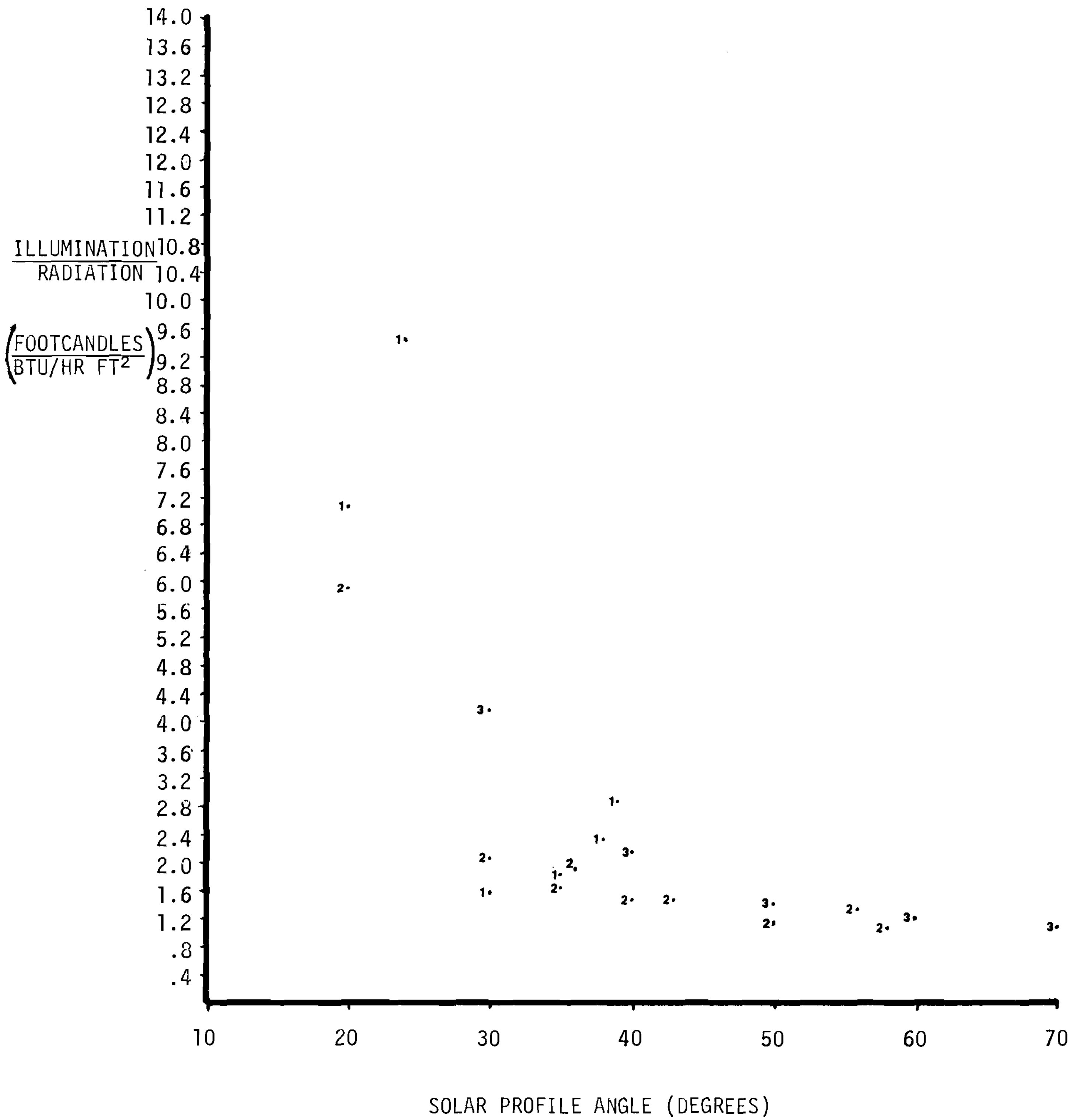
12. Marguerite Villecco, Steve Selkowitz and J.W. Griffith, "Strategies of Daylighting Design," AIA Journal, September 1979.

13. IES Daylighting Committee, "Recommended Practice of Daylighting," Lighting Design & Application, February 1979.

APPENDIX A
DAYLIGHTING MODEL DATA

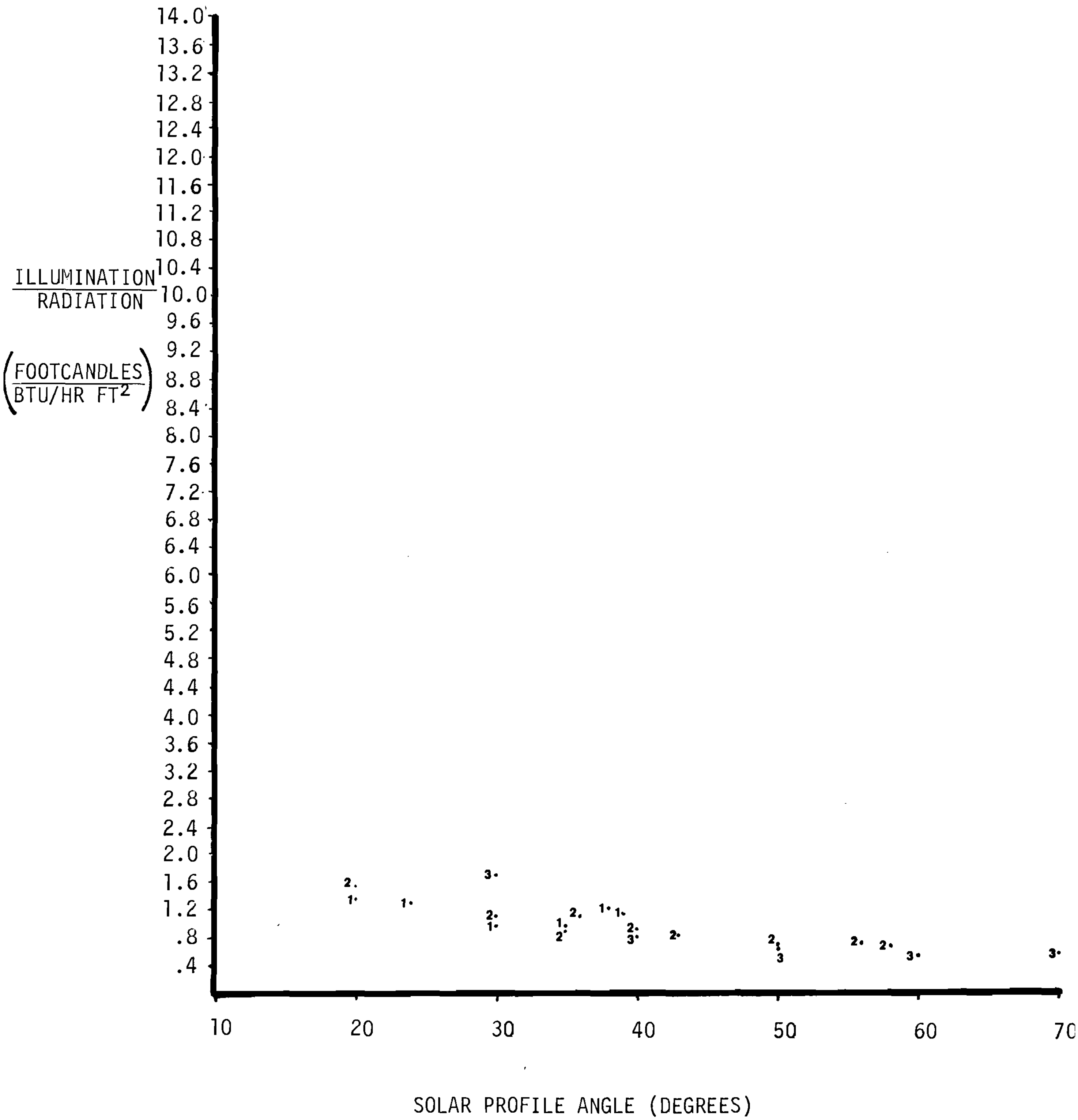

DIRECT GAIN
SOUTH MEASUREMENT
ILLUMINATION / RADIATION (FOOTCANDLES / BTU/HR FT²)
14.0
13.6
13.2
12.8
12.4
12.0
11.6
11.2
10.8
10.4
10.0
9.6
9.2
8.8
8.4
8.0
7.6
7.2
6.8
6.4
6.0
5.6
5.2
4.8
4.4
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
.8
.4
10
20
30
40
50
60
70
SOLAR PROFILE ANGLE (DEGREES)

DIRECT GAIN
MIDDLE MEASUREMENT

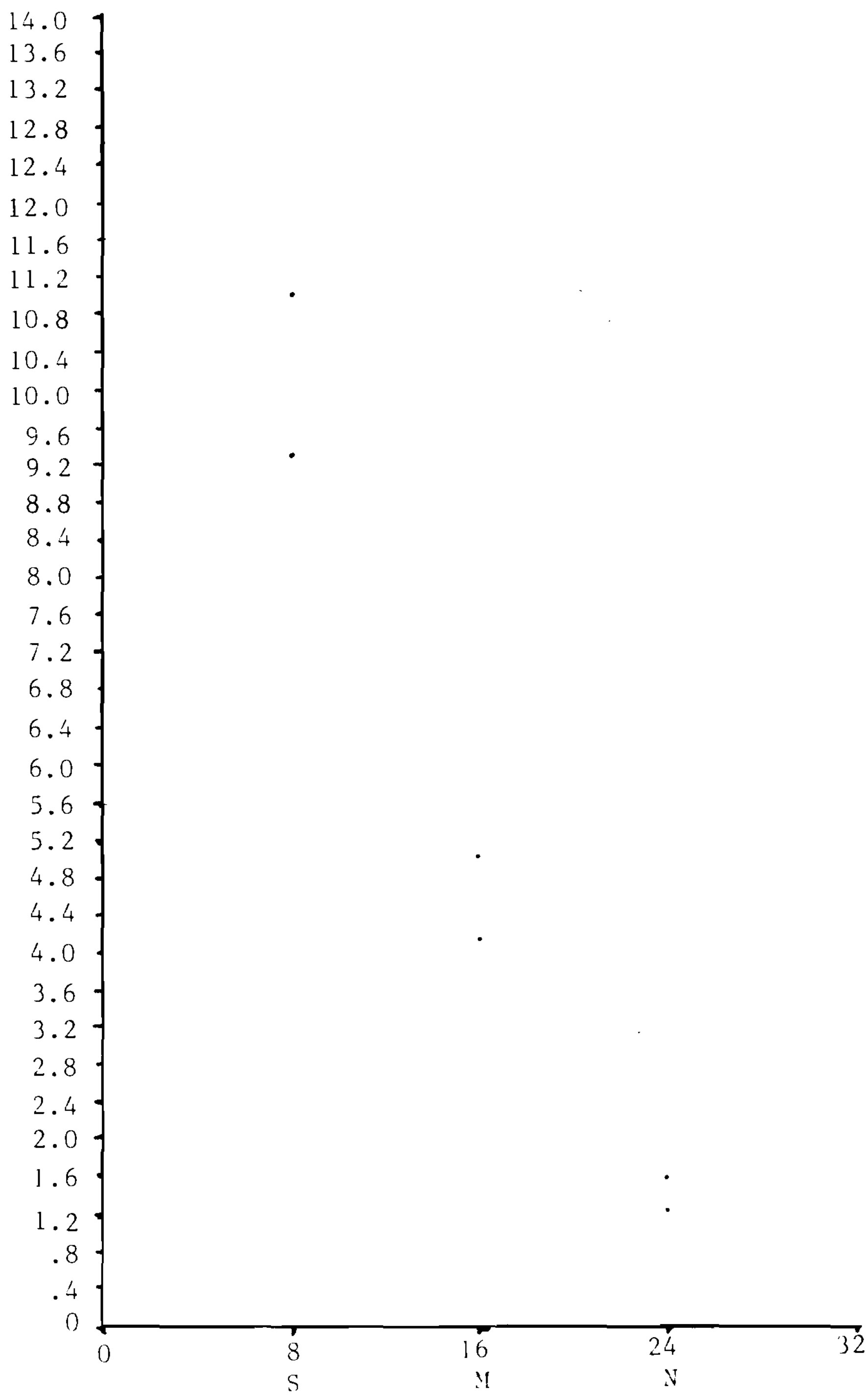


DIRECT GAIN

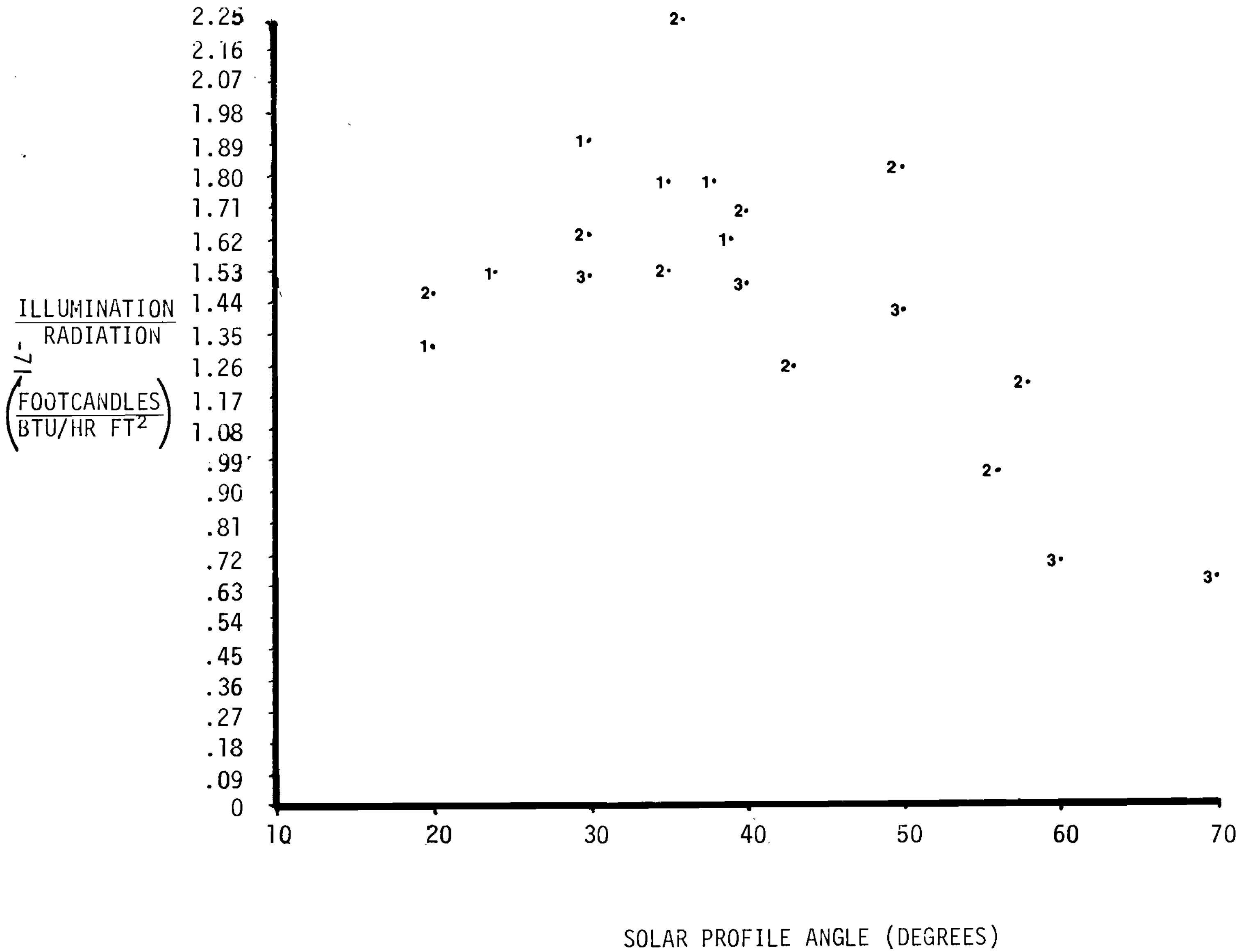
NORTH MEASUREMENT



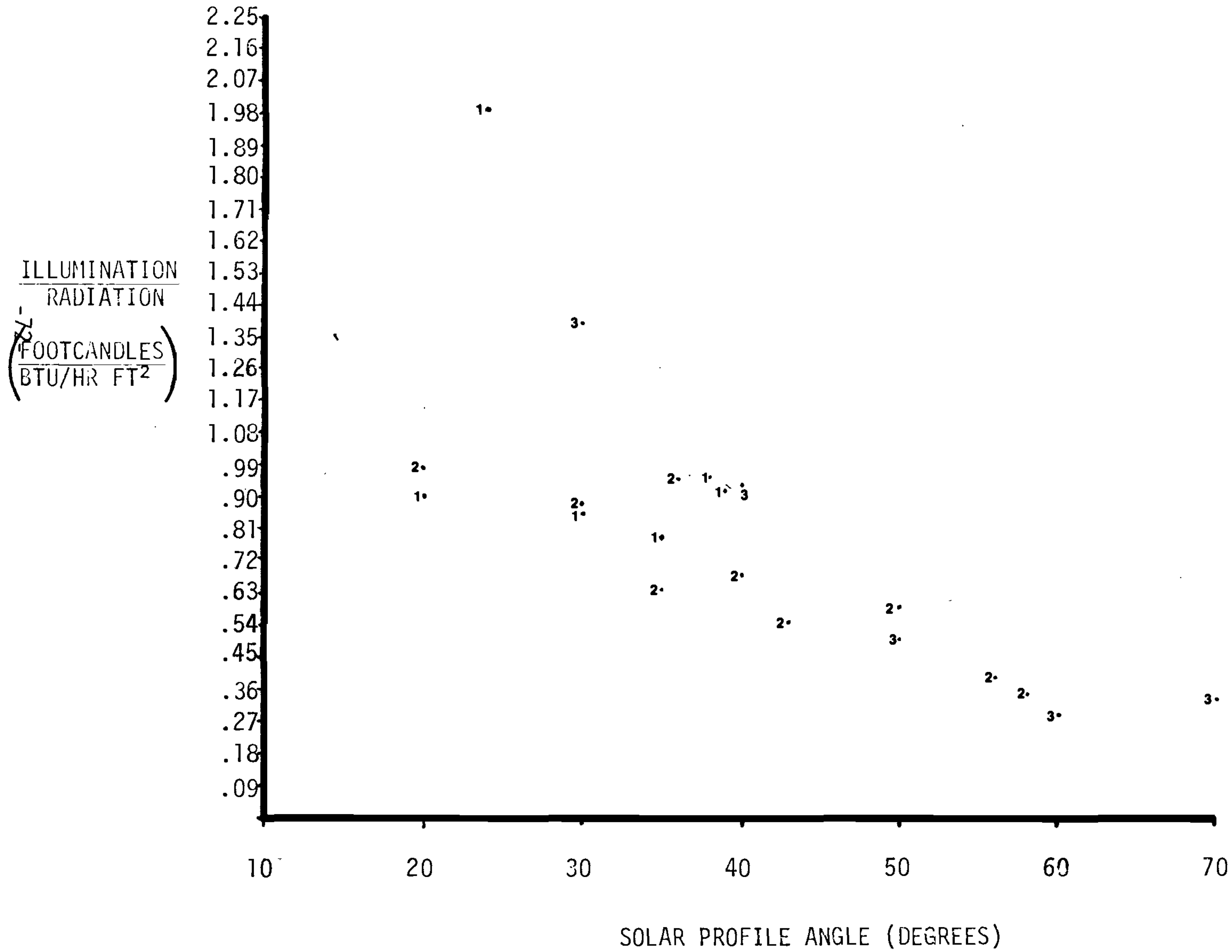
DIFFUSE DAYLIGHTING DATA
DIRECT GAIN



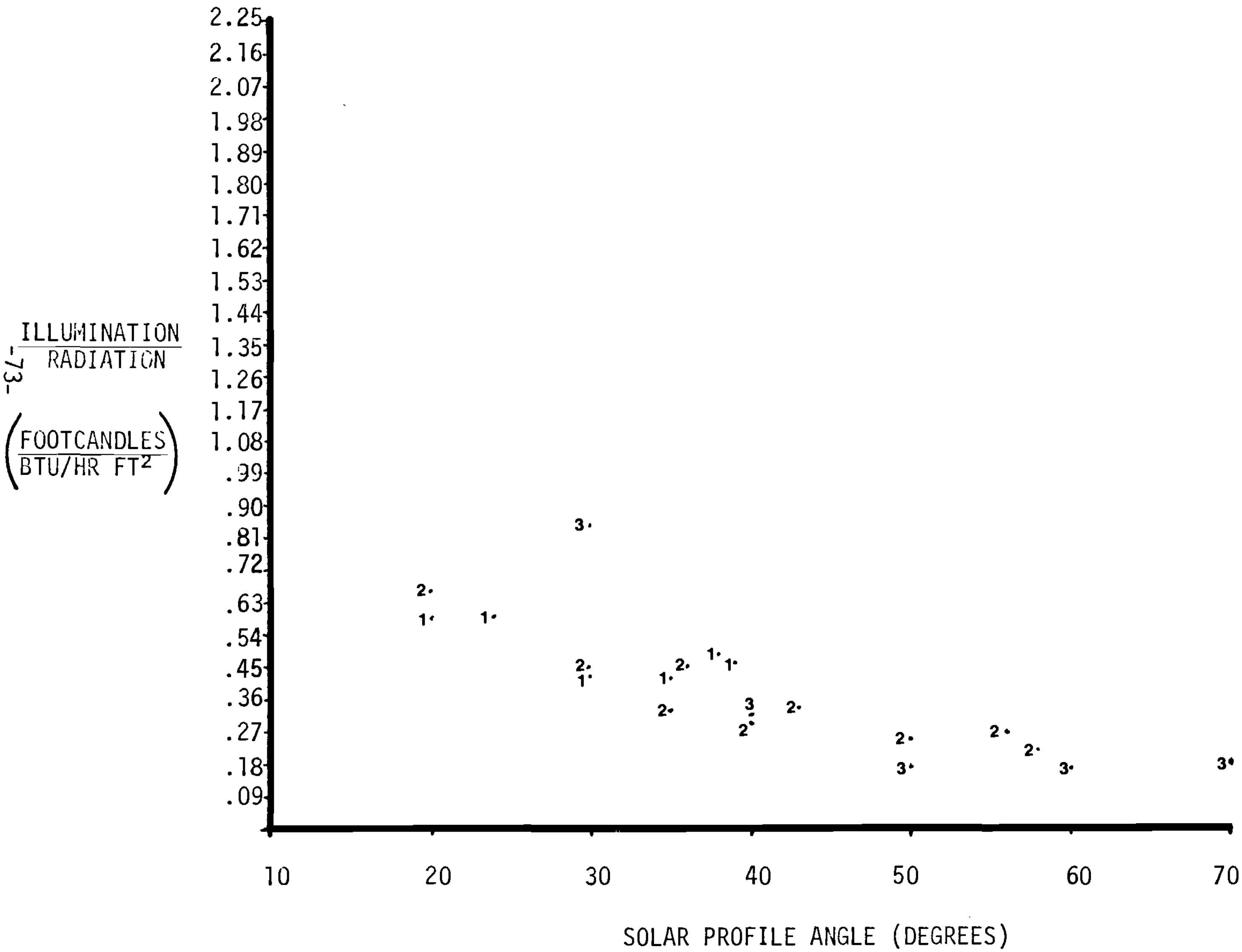
WATER WALL WITH LIGHT SHELF
SOUTH MEASUREMENT



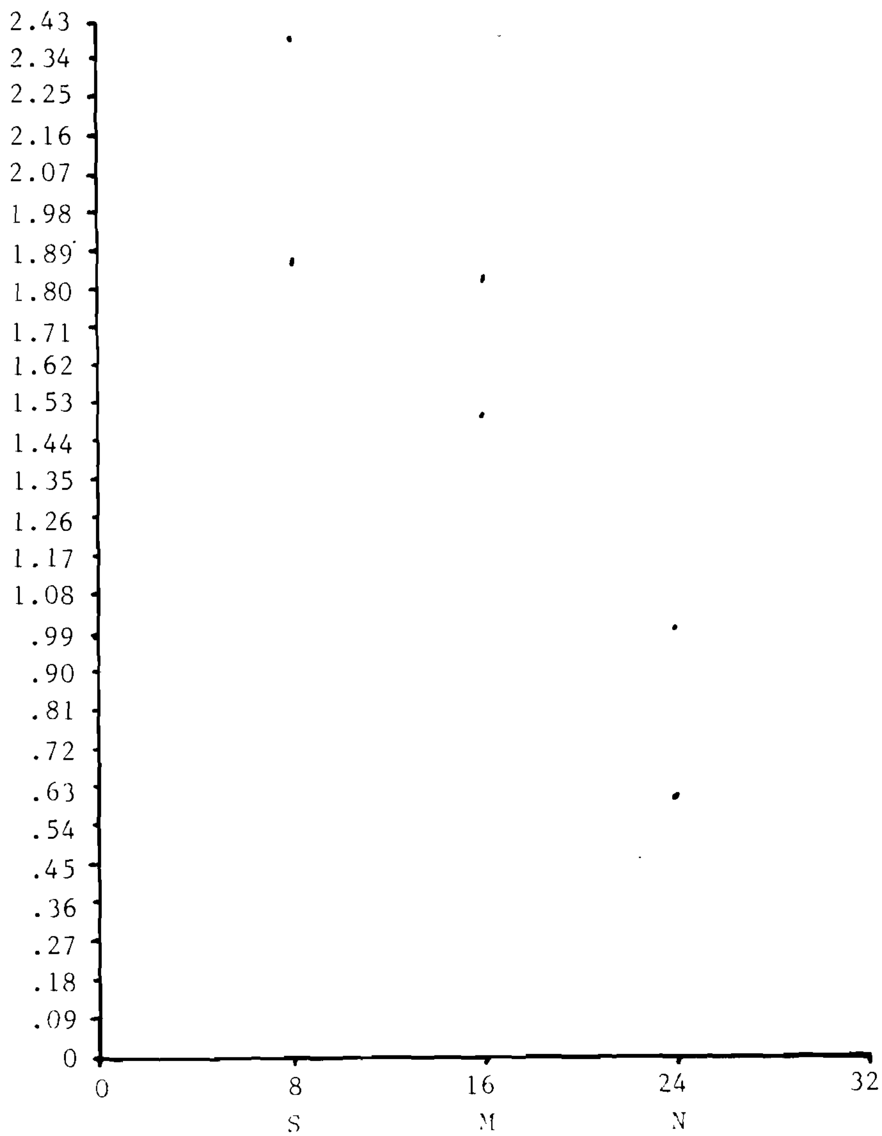
WATER WALL WITH LIGHT SHELF
MIDDLE MEASUREMENT



WATER WALL WITH LIGHT SHELF
NORTH MEASUREMENT



DIFFUSE DAYLIGHTING DATA
6' WATER WALL with LIGHT SHELF



```
      READ(5,*) IOPTSMR
      WRITE(6,*)" INDICATE INTERVALS PER HOUR"
      READ(5,*) INVPH
      WRITE(6,*)" INTERVALS PER HOUR:",INVPH
      WRITE(8,*)" INTERVALS PER HOUR:",INVPH
      WRITE(6,*)"LIST SIX SPECIAL DAYS FOR HOURLY DISPLAY"
      READ(5,*) IDAYIDM
      WRITE(6,*)"INPUT:SZA,CTILT"
      READ(5,*)SZA,CTILT
      WRITE(6,*)"SURFACE AZIMUTH ANGLE (DEGREES)=",SZA
      WRITE(8,*)"SURFACE AZIMUTH ANGLE (DEGREES)=",SZA
      WRITE(6,*)"COLLECTOR TILT (DEGREES)=",CTILT
      WRITE(8,*)"COLLECTOR TILT (DEGREES)=",CTILT
      WRITE(6,*)"FOREGROUND REFLECTANCE=",REFG
      WRITE(8,*)"FOREGROUND REFLECTANCE=",REFG
      WRITE(6,*)"INT HEAT GEN,DAY",QINTD,"     NIGHT",QINTN
C...SECQUENCE TO INITIALIZE PASSIVE SYSTEM PARAMETERS
C...USE DATA FILE FOR INPTOP EQUAL 1
1     CONTINUE
      WRITE(6,*)"CONTINUE????"
      READ(5,*) IOPTCON
      IF(IOPTCON.LE.0) GO TO 9999
      WRITE(6,*)"USE STRUCTURE PARAMETER FILE ?"
      READ(5,*) INPTOP
      IF(INPTOP.LT.1) GO TO 5
      READ(10,*) CVM
      READ(10,*) U
      READ(10,*) UALT
      READ(10,*) AUXH,AUXV,TADG,APRTURE,OVHNG,OHEAD
      READ(10,*) TSTON1,TSTON2,AVNTON
      READ(10,*) AFANON,AFANOF,FVFCT,TAPERC,VIND,VINN
      GO TO 6
5     CONTINUE
      WRITE(6,*)"INPUT:CVM&U&UALT&AUXH,AUXV,TADG,APRTURE,OVHNG,OHEAD"
      READ(5,*) CVM
      READ(5,*) U
      READ(5,*) UALT
      READ(5,*) AUXH,AUXV,TADG,APRTURE,OVHNG,OHEAD
      WRITE(6,*)"INPUT:TSTON1,TSTON2,AVNTON"
      WRITE(6,*)"INPUT:AFANON,AFANOF,FVFCT,TAPERC,VINN,VIND"
      READ(5,*) TSTON1,TSTON2,AVNTON
      READ(5,*) AFANON,AFANOF,FVFCT,TAPERC,VIND,VINN
C...USE A SUBROUTINE TO DEFINE THE SOUTH WALL
6     CONTINUE
      CALL DSW(U,UALT,NOGLZ,APRTURE,APRHYC,TADG,CVM)
C...REPORT ON PASSIVE PARAMETERS
      CONTINUE
      WRITE(6,9004) CVM
      WRITE(6,9005) U
      WRITE(6,9006) UALT
      WRITE(6,9007) AUXH,AUXV
      WRITE(6,9008) TADG
      WRITE(6,9010) OVHNG,OHEAD
      AWW=TADG*APRTURE
      ADG=APRTURE-AWW
```

```
      WRITE(6,9011) ADG,AWW,APRHYC
      WRITE(11,9018)
      WRITE(11,9011) ADG,AWW,APRHYC
      WRITE(8,9004) CVM
      WRITE(8,9005) U
      WRITE(8,9006) UALT
      WRITE(8,9007) AUXH,AUXV
      WRITE(8,9008) TADG
      WRITE(8,9010) OVHNG,OHEAD
      WRITE(8,9011) ADG,AWW,APRHYC
      DELT=1.0/FLOAT(INVPH)
      ADELT=DELT
      PI=ATAN(1.0)*4.0
      PIO2=PI/2.0
C...CONVERT THINAR TO RADIANS
      DO 7 I=1,10
7     THINAR(I)=THINAR(I)*PI/180.0
      SZA=SZA*PI/180.0
      CTILT=CTILT*PI/180.0
      SCTILT=SIN(CTILT)
      CCTILT=COS(CTILT)
      SSZA=SIN(SZA)
      CSZA=COS(SZA)
      DRSF=(1.0+CCTILT)/2.0
      RCDRSF=REFG*(1.0-DRSF)
C...INDICATE DOME AND FOREGROUND SHAPEFACTORS
      WRITE(6,*) 'DOME SF=',DRSF,'FOREGROUND=',RCDRSF
      WRITE(8,*) 'DOME SF=',DRSF,'FOREGROUND=',RCDRSF
      IF(IOPTSMR.GT.0) WRITE(6,9012)
      WRITE(8,9012)
      MTH=0
      IDAYCT=0
      TSPAVE=0.0
      ITSP=0
      IWE=0
      IDAYCT=1
11    CONTINUE
      TM4AVE=0.0
      ICTAVE=0
      DLHM=0.0
      MTH=MTH+1
      TMTHIGH=-1000.0
      TMTLOW=1000.0
      TAVE=0.0
      HTCA=0.0
      AUXHMT=0.0
      IHCT=0
20    READ(12,9001) IDAY,IHR,LST,ALPHA,PHI,IDIR,IDIF,IDIF1,ITDB
      TA=FLOAT(ITDB)
      TIME=TIME+1.0
      IHCT=IHCT+1
      CALPHA=COS(ALPHA)
      SALPHA=SIN(ALPHA)
      CPHI=COS(PHI)
      SPHI=SIN(PHI)
```

```
      DIR=FLOAT(IDIR)
      DIF=FLOAT(IDIF)
       COSTH=SCTILT*CSZA*CALPHA*CPHI+SCTILT*SSZA*CALPHA*SPHI
     &        +CCTILT*SALPHA
      IF(COSTH.GT.0.0) GO TO 201
      TAP=0.0
      GO TO 202
C...SECQUENCE TO EVALUATE BEAM REFLECTANCE
201   THINC=ACOS(COSTH)
      TAP=TBLU1(THINC,THINAR,TAARRAY,2,10)
202   CONTINUE
      CALL SHADE(SALPHA,CALPHA,PHI,SF)
      HDCA=DIR*TAP*COSTH*(1.0-SF)
      IF(HDCA.LE.0.0) HDCA=0.0
      HDIFCA=DIF*DRSF*TAD+(DIF+DIR*SALPHA)*RCDRSF*TADFG
      IF(HDIFCA.LE.0.0) HDIFCA=0.0
      CHTCA=HDCA+HDIFCA
C...BEGIN SIMULATION SECQUENCE
C...SET PARAMETERS AND VARIABLES
      TFINAL=TIME+1.0
      RADG=CHTCA*APRTURE
      IF((IDAY.LT.151).OR.(IDAY.GT.243)) GO TO 2032
      DO 2031 K=1,6
2031  TNEW(K)=TLAST(K)
      HAUXH=0.0
      DLH=0.0
      GO TO 2033
2032  CONTINUE
      HAUXH=0.0
      DLHC=0.0
      DO 2003 JII=1,INVPH
C     CALL RKINIT(FCN,3,TIME,TLAST,1.0E-3,2,2,IN,0,STORE,TFINAL,TNEW,
C    &            IRR)
      CALL QSIML(FCN,3,TIME,TLAST,1.0E-3,2,2,IN,0,STORE,TFINAL,TNEW,
     &            IRR)
      DO 205 K=1,6
205   TLAST(K)=TNEW(K)
      IRR=0
      HAUXH=HAUXH+HAUXP
      IF(IWE.LT.1) DLHC=DLHC+DLH*DELT
2003  CONTINUE
2033  CONTINUE
      TRAD=RADG+APRHYC*CHTCA
      HTCA=HTCA+CHTCA
      TAVE=TAVE+TA
C...ACCUMULATE SOME DAILY VARIABLES DURING SIMULATION
      AUXHMT=AUXHMT+HAUXH
      AUXHDY=AUXHDY+HAUXH
C...SECQUENCE TO DISPLAY SELECTED DAYS HOURLY
      IF(IDAY.NE.IDAYIDM(IDDAY)) GO TO 2001
      IF(IHR.EQ.1) WRITE(13,9015)
      WRITE(13,9016) IDAY,IHR,TA,TNEW,TRAD,HAUXH
      IF(IHR.EQ.24) IDDAY=IDDAY+1
2001  CONTINUE
      IF((LST.LT.800).OR.(LST.GT.1700)) GO TO 204
```

```
      DO 2051 K=1,6
      TPDAY(K)=TPDAY(K)+TNEW(K)
 2051 CONTINUE
      CNRTP=CNRTP+1.0
      TSPAVE=TSPAVE+TNEW(4)
      TSPSQ=TSPSQ+TNEW(4)*TNEW(4)
      ITSP=ITSP+1
      IF(IWE.LT.1) DLHM=DLHM+DLHC
      IF(TNEW(4).GT.TDYHIGH) TDYHIGH=TNEW(4)
      IF(TNEW(4).LT.TDYLOW) TDYLOW=TNEW(4)
      IF(IWE.EQ.1) GO TO 204
      TM4AVE=TM4AVE+TNEW(4)
      ICTAVE=ICTAVE+1
      IF(TNEW(4).GT.TMTHIGH) TMTHIGH=TNEW(4)
      IF(TNEW(4).LT.TMTLOW) TMTLOW=TNEW(4)
 204  CONTINUE
      HDAY=HDAY+TRAD
      TDAYAVE=TDAYAVE+TA
      AMHHBH(IHR)=AMHHBH(IHR)+HAUXH
      DLHA(IHR)=DLHA(IHR)+DLHC
C...SECQUENCE TO DISPLAY SIMULATION RESULTS
      IF(IHR.NE.24) GO TO 208
      DO 206 K=1,6
      TPDAY(K)=TPDAY(K)/CNRTP
 206  CONTINUE
      TDAYAVE=TDAYAVE/24.0
      TSPAVE=TSPAVE/ITSP
      TSPSTD=TSPSQ-FLOAT(ITSP)*TSPAVE*TSPAVE
      IF(TSPSTD.LT.0.0) TSPSTD=0.0
      TSPSTD=SQRT(TSPSTD/FLOAT(ITSP-1))
      IF(IOPTSMR.GT.0) WRITE(6,9009) IDAY,IWE,TDAYAVE,HDAY,TPDAY,
     &                      TDYHIGH,TDYLOW,TSPAVE,TSPSTD,AUXHDY
      WRITE(8,9009) IDAY,IWE,TDAYAVE,HDAY,TPDAY,TDYHIGH,TDYLOW,
     &              TSPAVE,TSPSTD,AUXHDY
      TDAYAVE=0.0
      AUXHDY=0.0
      TDYHIGH=-1000.
      TDYLOW=1000.
      HDAY=0.0
      IWE=0
      IDAYCT=IDAYCT+1
      IF(IDAYCT.GE.6) IWE=1
      IF(IDAYCT.GE.7) IDAYCT=0
      ITSP=0
      TSPAVE=0.0
      TSPSTD=0.0
      TSPSQ=0.0
      DO 207 K=1,6
      TPDAY(K)=0.0
 207  CONTINUE
      CNRTP=0.0
 208  CONTINUE
      IF(IDAY.EQ.MTEND(MTH).AND.IHR.EQ.24) GO TO 21
      GO TO 20
 21   CONTINUE
```

```
      TAVE=TAVE/IHCT
      T4A=TM4AVE/FLOAT(ICTAVE)
      AUXHANN=AUXHANN+AUXHMT
      WRITE(6,9003) MTH,TAVE,HTCA,AUXHMT,TMTHIGH,TMTLOW,T4A,DLHM
      WRITE(6,9013)
      DO 1900 K2=1,24
1900  AMHHBH(K2)=AMHHBH(K2)/1000.0
      DO 2201 K=1,4
      WRITE(6,9014) K,AMHHBH(K),DLHA(K),K+4,AMHHBH(K+4),DLHA(K+4),
     &              K+8,AMHHBH(K+8),DLHA(K+8),K+12,AMHHBH(K+12),
     &              DLHA(K+12),K+16,AMHHBH(K+16),DLHA(K+16)
2201  CONTINUE
      WRITE(6,9019)
      WRITE(6,9020) HCKARR
      IF((IOPTSMR.GT.0).AND.(MTH.NE.12)) WRITE(6,9012)
      WRITE(11,9003) MTH,TAVE,HTCA,AUXHMT,TMTHIGH,TMTLOW,T4A,DLHM
      WRITE(8,9003) MTH,TAVE,HTCA,AUXHMT,TMTHIGH,TMTLOW,T4A,DLHM
      WRITE(8,9013)
      DO 2202 K=1,4
      WRITE(8,9014) K,AMHHBH(K),DLHA(K),K+4,AMHHBH(K+4),DLHA(K+4),
     &              K+8,AMHHBH(K+8),DLHA(K+8),K+12,AMHHBH(K+12),
     &              DLHA(K+12),K+16,AMHHBH(K+16),DLHA(K+16)
2202  CONTINUE
      WRITE(8,9019)
      WRITE(8,9020) HCKARR
      IF(MTH.NE.12) WRITE(8,9012)
      DO 2101 K=1,24
      DLHA(K)=0.0
      AMHHBH(K)=0.0
2101  CONTINUE
      DO 2102 K=1,9
      HCKARR(K)=0.0
2102  CONTINUE
C...TO TERMINATE EXECUTION AT THE END OF JANUARY
C...ACTIVATE THE FOLLOWING STATEMENT
      STOP
      IF(MTH.EQ.12) GO TO 900
      GO TO 11
9001  FORMAT(I3,I2,I4,2F7.4,3I4,I3)
9003  FORMAT(/,/,I4,F11.2,F10.0,F14.0,12X,F6.0,F4.0,F6.0,F6.0)
9004  FORMAT(' THERMAL CAPACITANCES:',6F8.0)
9005  FORMAT(' BASIC CONDUCTANCES(B/HR/F-D)      ',8F5.0)
9006  FORMAT(' ALTERNATE CONDUCTANCES(B/HR/F-D):',8F5.0)
9007  FORMAT(' AUX HEAT(B/HR):',F10.2,'     AUX VENT(B/F-DEG/HR):',
     &       F10.2)
9008  FORMAT(' NOMINAL DISTRIBUTION OF SOLAR GAIN:',F10.4)
9009  FORMAT(2I4,F7.2,F10.0,F6.0,5F4.0,F6.0,F4.0,F6.0,F5.0,F9.0)
9010  FORMAT('  OVERHANG',F8.4,'  OVERHEAD',F8.4)
9011  FORMAT('  SOLAR WALL     :',/,20X,'DIRECT GAIN AREA     :',F8.4,/,
     &       20X,'WATER WALL AREA       :',F8.4,/,
     &       20X,'HYBRID COLLECTOR AREA:',F8.4)
9012  FORMAT('1',/,/,'  DAY WE   AVE   ABSORBED   T1   T2   T3  T4   T5  ',
     &    'T6       SPACE TEMP',12X,'HEATING',/,'         IND  TEMP    IRR',
     &  30X,'HIGH  LOW  AVE  STD')
9013  FORMAT(/,10X,'HEATING HISTOGRAM BY HOUR (10**3 BTU):',/)
```

```
     P 331 346
9014  FORMAT(6(I4,F5.0,F4.0))
9015  FORMAT("1",3/," DAY  HR  TA  T1  T2  T3  T4  T5  T6"
     &        ,"  IRRADIANCE  HEATING",/)
9016  FORMAT(I4,I3,F6.0,6F4.0,2F9.0)
9017  FORMAT("N")
9018  FORMAT("1")
9019  FORMAT(/,/,10X,"DISPLAY OF HEAT EFFECTS",/)
9020  FORMAT(4(F10.0),/,5(F10.0))
900   REWIND 10
      REWIND 12
      WRITE(6,*)"ANNUAL HEATING LOAD=",AUXHANN
      WRITE(8,*)"ANNUAL HEATING LOAD=",AUXHANN
      WRITE(11,*)"ANNUAL HEATING LOAD=",AUXHANN
      GO TO 1
9999  STOP
      END
```

```
      SUBROUTINE FCN(TIME,T,TPRIME)
      DIMENSION HCKARR(9)
      DIMENSION T(6),TPRIME(6),CVM(6),U(8),UALT(8),UNOM(8),R(2)
      COMMON /PARS/ CVM,UNOM,UALT,AUXH,AUXV,TADG,APRHYC,CHTCA
      COMMON /HCK/ HCKARR
      COMMON/QNT/ QINTD,QINTN
      COMMON /CCON/ DELT,TSTON1,TSTON2,AVNTON,VIND,VINN,AFANON,AFANOF,
     &              TAPERC,FVFCT
      COMMON /SWVARS/ RADG,TA,IHR,IWE,IMOR,IEVE
      COMMON /HAX/ HAUXP,DLH
C...DATA FOR HYBRID COLLECTOR, DOUBLE-GLAZED
      DATA FPRIME/0.77/,UNET/.0968/,ULOSS/0.89/
C...
C...INITIALIZE CONDUCTANCES
      DO 4 I=1,8
4     U(I)=UNOM(I)
      HAUXP=0.0
C...IS BUILDING OCCUPIED
      IOCU=1
      IF((IWE.GT.0).OR.(IHR.LT.IMOR).OR.(IHR.GT.IEVE)) IOCU=0
C...IF BUILDING IS OCCUPIED,THERMOSTSTS AT NOMINALS
      IF(IOCU.GT.0) GO TO 5
C...BUILDING UNOCCUPIED,SET BACK THERMOSTSTS,DISABLE CIRCULATOR
      TSTON=TSTON2
      FANON=-1000.0
      FANOF=-1000.0
      VNTON=1000.0
      GO TO 6
5     CONTINUE
C...BUILDING OCCUPIED,SET ALL CONTROLS TO NOMINAL
      TSTON=TSTON1
      FANON=AFANON
      FANOF=AFANOF
      VNTON=AVNTON
6     CONTINUE
      QINT=QINTN
      IF(IOCU.GT.0) QINT=QINTD
C...DISTRIBUTE IRRADIANCES
      R(1)=RADG*TADG
      R(2)=RADG-R(1)
C...
C...DETERMINE OUTPUT OF HYBRID COLLECTOR WALL
      QUSE=FPRIME*(CHTCA-ULOSS*(T(4)+7.5-TA))
      QLOS=-UNET*(T(4)-TA)
      IF(QUSE.LE.QLOS) QUSE=QLOS
C...SPEC AUX HEAT OR FORCED VENTILATION
C...INITIALIZE AUX
      AUX=0.0
C...AUX HEAT IF SPACE IS COOLER THAN SETTING
      IF(T(4).LT.TSTON) AUX=AUXH
      HAUXP=AUX*DELT
C...FORCE VENTILATE IF SPACE IS HOTTER THAN SETTING
      IF((T(4).GT.VNTON).AND.(T(4).GT.TA)) AUX=AUXV*(TA-T(4))
C...SPEC INFILTRATION OR NORMAL VENTILATION
      VINF=VINN*(TA-T(4))
      IF(IOCU.GT.0) VINF=VIND*(TA-T(4))
```

```
C...
C...CONTROL THE PASSSIVE COMPONENTS
C...IF SPACE IS COLD AND WALL IS HOT,FORCE VENTILATE
      IF((T(4).LT.FANON).AND.(T(1).GT.T(4))) U(2)=FVFCT*U(2)
C...IF SPACE IS TOO HOT, HALT VENTILATION
      IF(T(4).GT.FANOF) U(2)=0.0
C...IF SPACE IS HOTTER THAN WALL, HALT VENTILATION
      IF(T(4).GT.T(1)) U(2)=0.0
C...
C...ADJUST THE NIGHTIME EXPOSURE
      IF(IOCU.GT.0) GO TO 7
      R(1)=0.0
      R(2)=0.0
      U(1)=UALT(1)
      U(2)=UALT(2)
      U(6)=UALT(6)
      U(7)=UALT(7)
7     CONTINUE
C...CLOSE APERTURE WHEN SPACE IS OVERHEATED
      DLIND=1.0
      IF(T(4).LT.TAPERC) GO TO 21
      U(1)=UALT(1)
      U(2)=UALT(2)
      U(6)=UALT(6)
      U(7)=UALT(7)
      DLIND=-1.0
      QUSE=QLOS
      R(1)=0.0
      R(2)=0.0
21    CONTINUE
C...CLOSE APERTURE WHEN ESTIMATED TO BE A NET LOSER
      IF((R(1)+R(2)).GT.(U(1)*(T(1)-TA))) GO TO 22
      U(1)=UALT(1)
      U(2)=UALT(2)
      U(6)=UALT(6)
      U(7)=UALT(7)
      R(1)=0.0
      R(2)=0.0
22    CONTINUE
C...CALCULATE SOME HEAT RATES
      Q1=U(1)*(TA-T(1))
      Q2=U(2)*(T(4)-T(1))
      Q3=U(3)*(T(2)-T(1))
      Q4=U(4)*(T(3)-T(2))
      Q5=U(5)*(T(4)-T(3))
      Q6=U(6)*(T(5)-T(4))
      Q7=U(7)*(T(6)-T(5))
      QHC=QUSE*APRHYC
C...INSERT A CHECK TO VOID FORCED OVERHEATING
      IF(T(4).GT.TSTON) GO TO 30
      TP4MAX=68.-T(4)
      TPRIME(4)=(-Q5+Q6-Q2+AUX+QINT+VINF+R(2)+QHC)/CVM(4)
      IF(TPRIME(4).LT.TP4MAX) GO TO 30
      AMAX=CVM(4)*TP4MAX+Q5-Q6+Q2-QINT-R(2)+QHC-VINF
      IF(AMAX.LT.0.0) AMAX=0.0
      AUX=AMAX
```

```
      HAUXP=AUX*DELT
30    CONTINUE
C...CALCULATE RATES OF CHANGE OF TEMPERATURES
      IF(CVM(1).GT.0) GO TO 31
      TPRIME(1)=0.0
      TPRIME(2)=0.0
      TPRIME(3)=0.0
      GO TO 32
31    CONTINUE
      TPRIME(1)=(Q1+Q2+Q3+R(1))/CVM(1)
      TPRIME(2)=(-Q3+Q4)/CVM(2)
      TPRIME(3)=(-Q4+Q5)/CVM(3)
32    TPRIME(4)=(-Q5+Q6-Q2+AUX+QINT+VINF+R(2)+QHC)/CVM(4)
      TPRIME(5)=(-Q6+Q7)/CVM(5)
      TPRIME(6)=0.0
C...DETERMINE IF DAYLIGHTING IS ACTIVE
      DLH=1.0
      IF(DLIND.LT.0.0) DLH=0.0
      IF(RADG.LT.1200.0) DLH=0.0
C...INCREMENT THE ACCOUNTING ARRAY
C...HEAT LOSSES
      HCKARR(1)=HCKARR(1)+Q1*DELT
      HCKARR(2)=HCKARR(2)+Q7*DELT
      HCKARR(3)=HCKARR(3)+VINF*DELT
      IF(AUX.LT.0.0) HCKARR(4)=HCKARR(4)+AUX*DELT
C...HEAT GAINS
      HCKARR(5)=HCKARR(5)+R(1)*DELT
      HCKARR(6)=HCKARR(6)+R(2)*DELT
      HCKARR(7)=HCKARR(7)+QHC*DELT
      HCKARR(8)=HCKARR(8)+QINT*DELT
      IF(AUX.GT.0.0) HCKARR(9)=HCKARR(9)+AUX*DELT
      RETURN
      END
```

```
      SUBROUTINE QSIML(FCN,NR,TIME,TLAST,ERROR,IR,JR,IN,KR,STORE,TFINAL,
     &                TNEW,IRR)
      DIMENSION TLAST(6),TPRIME(6),TNEW(6),STORE(2,11)
      COMMON /SWVARS/ RADG,TA,IHR,IWE,IMOR,IEVE
      COMMON /AADEL/ DELT
      CALL FCN(TIME,TLAST,TPRIME)
      DO 1 J=1,6
      TNEW(J)=TLAST(J)+TPRIME(J)*DELT
1     CONTINUE
      TNEW(6)=TA
      RETURN
      END
```

```
      SUBROUTINE SHADE(SALPHA,CALPHA,PHI,SF)
C...THIS SUBROUTINE ESTIMATES TWO-DIMENSIONAL SHADING
C...OF BEAM RADIATION FROM A VERTICAL SURFACE
C...PARAMETERS OVHNG AND OHEAD ARE IN UNITS
C...OF THE HEIGHT OF THE GLAZED APERTURE
      COMMON /CSHADE/SZA,PI,OVHNG,OHEAD,PIO2
      PMA=PHI-SZA
      IF((PMA.GE.PIO2).OR.(PMA.LE.(-PIO2))) GO TO 10
      TANPM=SALPHA/(CALPHA*COS(PMA))
      Y=OVHNG*TANPM
      SF=Y-OHEAD
      IF(SF.GT.1.0) SF=1.0
      IF(SF.LT.0.0) SF=0.0
      RETURN
C...WHEN THE ANGLE BETWEEN THE SURFACE AZIMUTH AND THE
C...SUN IN THE HORIZONTAL PLANE EXCEEDS PI/2
C...SHADING MUST BE COMPLETE
10    SF=1.0
      RETURN
      END
```

```
      SUBROUTINE DSW(U,UALT,NOGLZ,APRTURE,APRHYC,TADG,CM)
      DIMENSION U(8),UALT(8)
      DIMENSION CM(6)
      DATA ASW/472.0/,RNIGHT/6.0/,UT/0.58/
      DATA RZ/2.04/
C...DEFINE THE GLAZING
      WRITE(6,*)"  ENTER NUMBER OF GLAZINGS"
      READ(5,*) NOGLZ
C...DETERMINE AREAS OF EACH COMPONENT
      WRITE(6,*)"PERCENT SOUTH WALL:DG,WW,HYCOL"
      READ(5,*) DGPC,WWPC,HCPC
      ADG=DGPC*ASW/100.0
      AWW=WWPC*ASW/100.0
      AHC=HCPC*ASW/100.0
      ACW=ASW-ADG-AWW-AHC
      IF(ACW.LT.0.0) WRITE(6,*)"WALL OVERCOMMITTED"
C...DEFINE EFFECTED CONDUCTANCES
      IF(NOGLZ.LT.2) UT=1.34
      IF(NOGLZ.LT.2) RZ=0.91
      U(1)=UT*AWW
      UALT(1)=U(1)*RNIGHT/(RNIGHT+AWW*U(1))
      U(2)=AWW*2.0
      UALT(2)=0.0
      U(3)=AWW*0.9
      UALT(3)=U(3)
      U(4)=U(3)
      UALT(4)=U(4)
      U(5)=AWW*1.24
      UALT(5)=U(5)
      UA=306.0+(ACW)/13.0+ADG/(RZ)
      UA2=306.0+(ACW)/13.0+ADG/(RZ+RNIGHT)
      U(6)=2.0*UA
      U(7)=U(6)
      UALT(6)=2.0*UA2
      UALT(7)=UALT(6)
C...POPORTION THE IRRADIANCE
      APRTURE=ADG+AWW
      APRHYC=AHC
      IF(APRTURE.GT.0.0) TADG=AWW/APRTURE
      IF(APRTURE.EQ.0.0) TADG=0.5
C...DEFINE THE THERMAL MASSES
C...EVALUATE AREA OF NON-PASSIVE SOUTH WALL
      ANPSW=590.0-(AWW+ADG+AHC)
C...CM1:EXPOSED MASS WALL
      CM(1)=12.48*AWW
C...CM2 AND CM3: INTERNAL NODES IN MASS WALL
      CM(2)=2.0*CM(1)
      CM(3)=CM(2)
C...CM4 IS AIR SPACE,FURNISHINGS,AND INTERIOR PANELING
      CM(4)=2712.0+ANPSW*0.33
C...ENQUIRE ABOUT ADDITIONAL INTERIOR MASS
      WRITE(6,*)"  CM4 IS",CM(4),"ANY MORE?"
      READ(5,*) AYMCM4
      CM(4)=CM(4)+AYMCM4
C...CM5 IS INTERIOR OF WALLS
      CM(5)=3750.0+ANPSW*.74
C...CM6 IS EXTERIOR SKIN OF BUILDING
      CM(6)=1033.0+ANPSW*0.44
      RETURN
      END
```